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THE SCIENTIFIC MONTHLY

APRIL, 1921

THE HISTORY OF PHYSICS*

By HENRY ANDREWS BUMSTEAD

LATE PROFESSOR OF PHYSICS IN YALE UNIVERSITY

THE beginnings of anything like a connected history of the science which is now called physics may be placed with considerable definiteness about the beginning of the 17th century and associated with the great name of Galileo. It is of course true that innumerable isolated facts had been known for many centuries which are now included among the data of this science; and many tools and simple machines which are now regarded as applications of physical principles had been devised and used. Even prehistoric man knew some of these—to his very great advantage. But, with one important exception which will be mentioned later, there was, in the ancient world, no connected body of knowledge in this field which can properly be called scientific. In this respect physics differs radically from mathematics, or astronomy, natural history, or medicine, each of which began its modern career with a store of scientific knowledge that had been obtained and put in order before the Renaissance.

The reason for this difference is doubtless to be found in the fact that the progress of physics is dependent, almost from the first step, on the method of experiment as distinguished from the method of observation. For some unknown psychological reason, the appreciation of the possibilities of experiment as an intellectual tool and the ability to make use of its technique appear very late in the history of human development. A few individuals like Archimedes understood and practiced it, and it is difficult to understand why the seed which they sowed proved sterile. Certain inhibitions, common (despite their very different temperaments) to the Greeks, the Romans and the men of the Middle Ages, seem to have prevented the infection from spreading from its original foci. I have no theory to offer as to the cause of the removal of these inhibitions during the 16th and 17th centuries; but whatever the cause we must, I think, recognize that

*A lecture delivered at Yale University, October 21, 1920, the fourth of a series on the History of Science under the auspices of the Yale Chapter of the Gamma Alpha Graduate Scientific Fraternity.

about that time a new factor made its appearance in the intellectual world which has survived and grown and has produced momentous results.

Some of you no doubt will be disposed to question the novelty which I have attributed to the methods used by Galileo and his successors. You will say with truth that men have been experimenting since long before the dawn of history; that by this means they improved their weapons, food, clothing, shelter and means of transport so that the enormous advantage in material surroundings which the Roman of the Augustan Age had over the prehistoric cave dweller may properly be said to be the result of a long course of progressive experimentation. But what I have, for the sake of making a distinction, called the experimental method in science is a very different thing from the slow empirical improvement of tools and appliances which went on before the beginnings of the modern era. The two kinds of activity differ fundamentally in the objects which they seek to attain and in the means they adopt for the accomplishment of their purposes.

The difference of objective is well illustrated by a remark of Galileo's at the very beginning of one of his most important works, the "Dialogue Concerning Two New Sciences." He says that he has long thought that the workmen in a great shop such as the Arsenal at Venice must know many things which would be of great service to philosophers if they could only be persuaded to use them. And he does in fact take such workman's knowledge got by the old empirical process and employ it for a purpose for which it had never been used before; to find out for example something about the laws and regularities governing the strength of materials and their dependence upon the size and shape of the object considered. The knowledge thus gained might or might not be useful to the workman, but it was of great consequence to the philosopher. Every scientific experiment has an objective of this kind—that is, every one that can properly be called an *experiment*, that has in it an element of originality and adventure into the unknown and that is not a mere routine test by known methods. Its purpose is much more general than the improvement of a tool or a telephone; and because of its generality it may incidentally do more to improve implements and technique in widely diverse fields of industry than thousands of experiments of the old cut-and-try kind extending over many centuries. The geometrical rate of increase resulting from this is sufficiently obvious from the industrial history of the past hundred years. Its continuance however is strictly conditioned upon the retention of the attitude of Galileo's philosopher; he may glance out of the corner of his eye at the by-products of his work but he must not think too much of them and must keep clearly in view his own philosophical mission.

As I have said the modern experimental method differs from the older empiricism in procedure as well as in purpose. The actual experiment is only a part of the process and does not come first in order of time; before it can be begun advantageously, there must be much careful thought and planning which often involves mathematics and deductive reasoning of the most old-fashioned kind. But there are no artificial hazards and rules of the game, such as those which the Greeks were so fond of imposing in mathematical problems. Any sort of logic (or the lack of it) is permissible since the final test is to be the experiment and not consistency of argument; it will indeed be a test of the premises no less than of the reasoning process. The greatest masters are those who make most use of apparently non-logical processes—intuitions and "hunches" which are perhaps the results of subconscious reasoning from data but dimly perceived.

The experiment itself is an observation made under highly artificial and carefully prearranged conditions, and it is this which gives the method its greatest advantage over simple observation of natural phenomena. This is well illustrated by Galileo's work upon the principles of mechanics and in their application to the particular case of the motion of falling bodies. Centuries of inescapable observation of moving bodies had led to no correct idea of the simple laws underlying their behavior, because these laws had been obscured by the effect of friction—a secondary condition of the problem. Galileo's experiments consisted in reducing these effects until the true nature of the phenomena could be observed. The famous experiment at the Leaning Tower of Pisa was a spectacular demonstration of one point of his theory designed to confute his Aristotelian critics; but the really important and fertile experments were quite simply arranged with the help of iron balls, inclined tracks, boards, nails and bits of string. With the simplest material means he laid the foundations of dynamics and, with it, those of physical science as a whole. Lagrange remarks that Galileo's contributions to mechanics "did not bring him in his lifetime as much celebrity as those discoveries which he made about the system of the world, but they are to-day the most enduring and real part of the glory of this great man. The discoveries of Jupiter's satellites, of the phases of Venus, of sun spots, etc., needed only telescopes and assiduity; but extraordinary genius was needed to disentangle the laws of nature from phenomena which are always going on under our eyes, but of which the explanation had always eluded the search of philosophers."[1]

[1]The necessary brevity of this lecture may result in giving the impression that Galileo had no forerunners. This is of course not the case. Archimedes has already been mentioned—a lonely genius who laid firmly the foundations of the statics of solids and liquids. Stevinus, sixteen years older

The world was ready for the structure which was to be erected upon the foundations laid by Galileo In the next generation, Torricelli in Italy and Pascal in France showed by bold reasoning and experimentation that Nature's *horror vacui* was due to the weight of the atmosphere; while Guericke in Germany and Boyle in England discovered other important properties of gases. In dynamics, the direct succession fell to Christian Huygens of Amsterdam, a natural philosopher of very high rank and a worthy successor of Galileo. He completed the theory of the pendulum and by its use determined the acceleration of gravity; invented and constructed the pendulum clock and escapement, discovered the theorems of centrifugal force, and was the first to use what is now called the principle of *vis viva* or kinetic energy. His investigations in optics are also of great importance and he was one of the first proponents of the wave theory of light.

To try to give in a small fraction of a single lecture any adequate account of the mighty deeds of Newton is, of course, to attempt the impossible. Fortunately the main features of his achievements are so familiarly known that a brief recapitulation is all that is necessary. Born in 1642, the year of Galileo's death, his genius developed with extraordinary rapidity. It appears to be quite certain that the essential parts of all his great discoveries were made before he was twenty-five years old, although most of them were published much later. The delay was due partly to lack of facilities for publication but mainly to Newton's carefulness in verification and in working out all possible consequences of his hypotheses. His first great discovery (made in the year in which he received the bachelor's degree at Cambridge) was the "direct and inverse methods of fluxions" which are in all essentials identical with the differential and integral calculus, but with a less convenient and fertile notation. This discovery belongs of course primarily to the history of mathematics; but both physics and astronomy may proudly claim it as belonging partly to them for two reasons; first, because it was the exigencies of their problems which led directly to it; and second, because it was an absolutely indispensable tool for the mechanical and astronomical discoveries of Newton and his successors. In the same year (1665) Newton "began to think of gravity extending to the orb of the moon"; he soon found from one of Kepler's laws that the forces which keep the planets in their orbits must vary inversely as the square of their distances from the sun. He applied this rule to the earth and moon and found an approximate agreement between the force necessary to keep the moon

than Galileo, made notable additions to the Archimedean statics. And a century earlier Leonardo da Vinci (a miracle of versatility) had made important discoveries in statics, and had found the true law of the refraction of light. Most of Leonardo's scientific work, however, remained buried in his manuscript notes and has only recently been revealed to the world.

in her orbit and the force of gravity at the surface of the earth. "All this," says Newton in later life, "was in the two plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since."

During the twenty-one years which elapsed before the publication of the *Principia* in 1687, Newton, in the midst of other duties and of investigations on other subjects, recurred again and again to the astronomical and dynamical problems which had engaged his youthful attention. It was only after ten or twelve years that he cleared up the difficulties of centrifugal force (Huygens' previous work being then unknown to him) and thus discovered that the two remaining laws of Kepler were consequences of his gravitational law. In the last three or four years of the period under consideration he appears to have worked steadily at the development of the subject and to have discovered the large number of important theorems and relations which make the *Principia* the most stupendous and overwhelming publication in the history of science.

In all this work there are three streams of discovery which may be separated by logical analysis, but which are so closely intermingled that it is difficult to see how any one of them could have gone on without the other two. Nobody has ever been able to believe that Newton could have extended the Galilean dynamics to the intricate motions of the planets except by the aid of the method of fluxions or its equivalent; and certainly nothing could have been done without a knowledge of the law of gravitation. On the other hand, the solution of astronomical problems required and facilitated a more exact formulation of the principles of mechanics than Galileo had been able to give; although mathematically intricate, they are dynamically simpler than terrestrial problems since no appreciable frictional or dissipative forces are present; and they furnish tests and verifications of dynamical laws of far greater accuracy than can be obtained in any other way.

Under such conditions it seems futile to attempt to decide whether physics is most indebted to Newton for the formulation of the laws of motion, for the discovery of the law of inverse squares, or for the invention of the fluxional calculus. Any one of the three (if it could have been produced alone) would have made his name immortal; the fact that we owe all three to one person places him upon a pinnacle of greatness which has not even been approached by any other man of science.

I must not neglect to mention also Newton's contributions to optics which, while not of the fundamental importance of those we have just been discussing, were nevertheless worthy of their author. I need only to recall to your memory that he investigated the composition of white light, the colors of thin films, diffraction, and the possibilities of

achromatism in refracting telescopes. He was not infallible; for he decided that it was impossible to make an achromatic refractor, and he supported the corpuscular theory of light against the undulatory theory of Huygens. In both cases, however, the evidence obtainable in his time strongly supported his position; and I think it was this, rather than the mere authority of his name, which caused the corpuscular theory to prevail during the following century.

In the eighteenth century the development of mechanics and of gravitational theory was carried on by the three Bernoullis, Euler, Clairaut, d'Alembert and others. This development reached its culmination near the end of the century in the publication of Lagrange's "Mécanique Analytique" and of the "Mécanique Céleste" of Laplace—works which for completeness and finish have seldom if ever been excelled. The period was not characterized by new discoveries of the first magnitude but by the careful working out of the theories founded by Galileo and Newton and the perfection of mathematical methods for dealing with complicated problems. This was an admirable preparation for the great outburst of discovery which began toward the end of the eighteenth century and was continued still more conspicuously in the first years of the nineteenth.

In other branches of physics and in chemistry, the ground was also being prepared in a different way by the accumulation of experimental facts and relations which formed the raw material for the generalizations of the period which was to come, and served as starting points for notable advances. It is necessary therefore to go back and to trace briefly the course of the tributary streams of discovery which were soon to join the main current. We shall have to consider what had been learned about magnetism, electricity, light and heat.

The ancients were acquainted with the curious property possessed by the lode-stone of Magnesia of attracting iron, and also knew that when amber was rubbed it attracted bits of straw and other light bodies. Nothing came of this knowledge for centuries; but at some unknown time prior to the Crusades, the north-seeking property of the magnetized needle was discovered and the mariner's compass was invented. The science of magnetism was indeed almost the only part of physics that made any progress during the Middle Ages. In the thirteenth century Petrus Peregrinus of Picardy, experimenting with a spherical lode stone and a needle, found that the stone possessed two "poles" which appeared to be the seat of the magnetic power.

The true founder of both magnetic and electric science, however, was William Gilbert of Colchester, physician to Queen Elizabeth. Twenty-four years older than Galileo, Gilbert must be regarded as one of the pioneers of the experimental method. His work had not the scope and depth which characterized that of the great Italian, nor were

its consequences so immediate and so revolutionary; but he was nevertheless a truly scientific experimenter and, considering the time in which he lived, we must regard him as a prodigy of originality. He showed quite conclusively that the behavior of the compass was due to the fact that the earth itself was a great magnet. For two thousand years it had been supposed that amber alone was capable of being excited by friction to attract other bodies; Gilbert found that many bodies could be thus excited and that among them were such commonplace substances as glass, sulphur and resin. His experiments and his reasoning were sound, and he devised a hypothesis of "electric effluvia" which was helpful to electrical science for a long time.

During the eighteenth century the experimental knowledge of both electricity and magnetism progressed rapidly. The conduction of the electrified state by metals was discovered by Stephen Gray; the Leyden jar was invented; du Fay found that there existed two opposite states of electrification which he called vitreous and resinous and that these behaved, as to attractions and repulsions, like the two poles of a magnet. America made her first contribution to physics in the very important work of Benjamin Franklin. Toward the close of this period of activity the doctrines of electric effluvia and of Cartesian vortices had been definitely replaced by the theory that the forces observed were due to action at a distance between charges of a single electric fluid and matter (Franklin), or to a similar action between two fluids (Coulomb). Eventually the law of variation of this force with the distance was experimentally determined by Coulomb and found to be the familiar inverse square relation of Newton. The same law was shown by Coulomb to hold for the forces between magnetic poles also; and either one, or two, magnetic fluids had to be predicated to account for the variation in the strength of magnets. Indeed the application of gravitational theory to these forces rendered inevitable the introduction of such imponderable fluids to take the place of the material masses which play the same rôle in the case of gravitation.

I have already mentioned briefly Newton's researches in optics and his adherence to the corpuscular theory in which he was followed by most philosophers. This introduced another "imponderable" which was however supposed to consist of excessively minute discrete corpuscles instead of a continuous fluid. Many important optical phenomena had been discovered. Descartes had published the mathematical law of refraction which however was not his own discovery but was apparently communicated to him by Snell of Leyden; Newton had discovered and properly interpreted the composite nature of white light and had investigated the simpler cases of diffraction and of what is now called interference; Huygens had observed double refraction in Iceland spar and had given the proximate explanation of

it (on the wave theory) which is still current; and he observed that the two beams which had passed through the spar differed from each other and from ordinary light in the peculiar way which we now indicate by calling them polarized. Time is lacking for any discussion of the ingenious arguments by which the two rival theories of light were supported.

The quantitative study of heat begins with Galileo's construction of the first thermometer—an air-thermometer of considerable sensitiveness but of inconvenient design. Improvements of one kind or another were made by many men and the fixity of certain temperatures (such as that of melting ice) was established. The first really reliable thermometers were made by Fahrenheit in the first quarter of the eighteenth century. All of the early thermal experiments and theories were confused by the failure to distinguish clearly between temperature and quantity of heat, and by the great and apparently capricious differences between the heat capacities, or specific heats, of different substances. All these difficulties were finally cleared up in a masterly manner by Joseph Black near the end of the period we are considering. He established calorimetric measurements on a firm basis, and showed quite clearly that in all such experiments heat behaves like a substance which passes from one body to another and sometimes becomes "latent" for a time (as when ice melts) but which is never created or destroyed. All these conclusions are true within the range of Black's experiments; and it was only at a later date that the exceptions were seen to be of great importance and not explicable by appealing to latency or to a variation in heat capacity. What was known at that time thoroughly justified a substantial theory of heat as the most convenient hypothesis available; and thus another imponderable fluid took its place as a respectable and useful article in the physicist's creed. Many unavailing attempts were made to show the identity of two or more of these hypothetical substances. Thus, on account of the phenomena of radiant heat, it was proposed to identify caloric with the light corpuscles; but the fact that light passed through glass while radiant heat did not, was an insuperable obstacle to this view. There was always in the background the possibility that both heat and light were forms of motion, but at the period now under consideration the substantial theories undoubtedly held the field. This state of things led to very sharp boundaries between the different fields of physics and discouraged the natural inclination to apply the principles of dynamics (which by this time had come to seem almost intuitive) to other physical phenomena. There was no great encouragement to apply the principles of mechanics to the imponderables; so far as experiment showed they lacked not only the conspicuous property of weight but also the most essential dynamical characteristic of

ordinary matter, inertia. The natural and fertile method of dealing with them was to take as postulates for the mathematical development of the subject certain empirical relations as simple and fundamental as possible. It was not until the establishment of the conservation of energy in the late forties of the nineteenth century that the barriers between the different "physical forces" were broken down.

The intervening period however was one of brilliant discovery in both mathematical and experimental physics. In the theory of heat two works of this period must at least be mentioned. In 1822 Joseph Fourier publisher his *Théorie Analytique de la Chaleur* a work of genius which has had a profound effect in almost all branches of theoretical physics and upon pure mathematics as well. A still more momentous event in the history of science was the publication in 1824 of Carnot's *Réflections sur le Puissance Motrice du Feu.* His primary purpose was the investigation of the efficiency of heat engines which had recently become a matter of interest owing to the increasing use of the steam engine invented by Newcomen and Watt. In this paper Carnot makes use of an analogy; he saw that the production of work by an engine might be regarded as due to the fall of caloric from a higher to a lower temperature just as the work of a water mill is a consequence of the fall of water from a higher to a lower level. He follows a course of reasoning so simple yet so effective that it seems inspired; it is based upon the denial of the possibility of perpetual motion which even at that time was a pretty firmly established empirical fact owing to the consistent failure of all attempts to produce such motion. He thus establishes the general principle which is now called "the second law of thermodynamics" and which is of far wider application than could have been imagined by Carnot or any of his contemporaries. For it happens that nearly every phenomenon in the physical universe is attended by an evolution or absorption of heat and is therefore subject to the second law. It governs every chemical reaction as was shown by Willard Gibbs fifty years later, and the physical and chemical processes of life. It sets bounds to cosmological speculations and to forecasts of the future of the human race. Not the slightest deviation from it has ever been observed and the probability of such deviation is so minute that it must be regarded as one of the most firmly established of scientific facts.

In electrostatics and magnetism this period was marked by the development of the mathematical consequences of Coulomb's discovery that the inverse square law applies to these forces. Much of the gravitational theory could be taken over directly while the special applications to electricity were made by Poisson, Green, and others. In the meanwhile however another set of electrical phenomena had appeared. In 1791 Galvani, professor of anatomy at Bologna, gave an

account of his experiments on the contraction of frogs' legs when touched with two different metals in series and, with much ability, supported the view that it was an electrical manifestation. He naturally supposed that the origin of the electrical disturbance was in the animal tissues. This was combatted a year later by Volta who referred the seat of the forces involved to the point of contact between the dissimilar metals, and gave good evidence that they were electrical. The effects however were very small, and interest flagged until 1800 when Volta invented the "pile" by means of which very appreciable results could be obtained. This at once excited much attention; and in the same year Nicholson and Carlisle in England in experimenting with the Voltaic pile observed the decomposition of water by electrolysis and shortly afterward Humphrey Davy advanced the chemical theory of the pile, which, after many years of struggle, eventually superseded the contact theory of Volta. There was a rapid advance in the knowledge of the electric current, of batteries, and of the electrolytic process. These experiments produced a profound effect upon chemistry through the electrochemical theory of Berzelius; and although this has long been given up, the most modern theories have, in a different form, reverted to the view that chemical forces are of electrical origin.

Many attempts had been made to discover some connection between the phenomena of electricity and those of magnetism but all had failed until 1820 when Oersted of Copenhagen observed and correctly described the action of an electric current upon a magnet brought near it. As soon as the news of this observation reached Paris, Ampère began the series of investigations which was to render his name immortal in electrical science. Within a week he had demonstrated to the Academy the attractions and repulsions of parallel currents; and during the ensuing three years his brilliant experimental and mathematical researches laid a sure and firm foundation for all the subsequent developments in electrodynamics. As was to be expected, he based his investigations on the Newtonian model, by using current-elements acting upon each other by forces in the line joining them. Again the law proved to be that of the inverse square; but the fact that the attracting elements were directed quantities added many difficulties which, in the state of mathematical science at that time, gave ample scope to the "Newton of electricity" for the display of his genius. The vector relations involved in the statement of his problem caused an indeterminateness which later gave rise to many rivals to Ampère's expression for the force between current elements. These all gave the same result when integrated around closed circuits which alone were amenable to experiment; and no one could succeed in devising experiments which would discriminate between them. One of these rival theories, that of Weber, is interesting as being in some respects similar to the modern theory of electrons.

Great as is the debt which electrical science owes to Ampère, it is exceeded by its obligation to Faraday whose marvellous experimental skill and instinctive perception of the inner nature of phenomena are still the wonder and admiration of all men of science. At twenty-one years of age he was a journeyman book-binder who had educated himself in some degree by reading the books which he was given to bind. The Encyclopaedia Britannica aroused his interest in science and he applied to Davy for employment in the Royal Institution. For a number of years, as Davy's assistant, his chief work was in chemistry; but Oersted's discovery turned his thoughts toward electricity and thereafter it was his principal field of work. In 1831 he made the capital discovery of the induction of currents which is not only of the most fundamental consequence to the theory of electromagnetism but is the foundation of the innumerable practical applications of electricity to the uses of man. Of his many other discoveries I shall mention only two; the quantitative laws of electrolysis which bear his name and which gave the first suggestions of an atomic theory of electricity, and the specific inductive capacity of dielectrics.

Because of the deficiencies of his early education, Faraday never acquired the technique of the mathematician. But, as Maxwell has pointed out, his mind was admirably fitted for dealing with quantitative relations. He overcame the handicap under which he suffered by devising his own methods of representing the quantitative side of phenomena—methods which not only enabled him to achieve his unparalleled success as a discoverer but which are so useful to others that they have held the field in elementary instruction in electromagnetism as well as in the most complicated problems of modern electrical engineering. His lines of force were to him real entities and he conceived of all forces as being transmitted from point to point in a continuous medium. The idea of action at a distance was repugnant to him. It is indeed to most physicists but Faraday was not tempted as most of us are to use distance forces because of their mathematical convenience and thus to escape the prodigious difficulties of imagining a medium with the necessary properties to account for the forces. Faraday's prejudices were to have important consequences in the next generation as we shall see when we come to speak of Maxwell.

The year 1800 is an important date in the history of optics as it is in that of electricity; for in that year Thomas Young took up the cudgels for the wave theory of light which had been almost completely neglected since the time of Huygens. In the following year he explained the colors of thin films (Newton's rings) by means of the "interference" of waves; and in 1803 he applied the same idea to certain problems of diffraction, but in a way which was afterward proved to be wrong. He was drawn into a controversy with the great Laplace

who had worked out a theory of double refraction on the corpuscular basis; and for a dozen years or more Young found little sympathy and support for his views among scientific men of established reputation. Indeed he was far from having a good case; the explanation of diffraction was not satisfactory; there was no explanation of polarization since waves in the tenuous and fluid ether were quite naturally supposed to be compressional like sound waves in air; and, for the same reason, no satisfactory explanation of double refraction appeared to be possible.

The first defect was remedied by the work of Fresnel, presented to the Paris Academy in 1816, in which the author began that brilliant series of experimental and mathematical investigations which left the wave theory completely victorous over its rival. He gave the true theory of diffraction by a slit and a wire and showed that it agreed with the results of his experimental measurements. Poisson, who was one of the referees of his paper, noted the fatal objection that Fresnel's theory would require a bright spot in the exact center of the shadow of a circular object. When, however, the matter was put to the test of experiment under suitable conditions, the bright spot was found and this naturally produced a reaction in favor of Fresnel's theory. It appears to have been Young who took the bold step of suggesting that the vibrations in light waves were transverse and that thus polarization could be explained. Fresnel at once took up this suggestion and succeeded in bringing into line all the intricacies of crystalline refraction, including that in biaxial crystals which had been discovered a few years before by Brewster and had been a stumbling block to all other theories. Later he took up the theory of reflection and refraction by ordinary transparent bodies with equal success; and since the completion of his series of memoirs there has never been a doubt in the mind of any competent person that light has the kinematical properties of transverse wave motion.

On the dynamical side, however, matters were not so clear. Only a solid can transmit tranverse elastic waves and it was difficult to believe that the ether could be a solid and yet allow the free motion of material bodies through it without the slightest detectable resistance. This was the origin of the great problem of the existence and properties of the ether—a problem which has excited the most eager interest of physicists for a hundred years and is still with us. Many of the most important discoveries, mathematical and experimental, have arisen from attempts at its solution. It at once stimulated the mathematical study of the theory of elastic solids and of the applicability of this theory to the phenomena of light. The work of Gauchy, Green, McCullagh, Stokes and Kelvin in this field may be said to have created a new era in mathematical physics and even in mathematics itself; for

the treatment of continuous media required methods which differed in many ways from those appropriate to distance forces of the Newtonian type. It was also the first attempt to apply in all strictness the principles of dynamics to natural phenomena outside the restricted field of mechanics proper. It was never perfectly successful, but so nearly that there was constant encouragement to persevere. We shall have occasion to look at a second phase of this gallant attack upon the mysteries of Nature when we come to deal with the work of Clerk Maxwell.

About the middle of the century occurred the epoch-making discovery of the conservation of energy which brought all kinds of physical and chemical phenomena into much more intimate relation with each other than had previously been suspected. Incidentally, it greatly strengthened the tendency, of which I have just spoken, to seek for a strictly dynamical foundation for all such phenomena.

The discovery arose primarily in a reconsideration of the nature of heat, and its history is so curious and interesting that it is with regret that I recognize the impossibility of giving an adequate account of it within the limits of this lecture. As we have seen, the belief that heat was a substantial fluid had prevailed for many years and had proved useful; but there had always been a suspicion (extending back to the time of Hooke and Newton) that it might be an effect of motion—either of the fine particles of which ordinary matter was made up, or of light-corpuscles within matter. At the end of the eighteenth century, Count Rumford had made experiments which ought to have started things in the right direction, but were disregarded. Carnot himself, in some posthumous notes which were not published until 1878, gave so clear an outline of the true theory that we cannot doubt that the course of science would have been greatly altered, as Mach remarks, if Carnot had not died of cholera in 1832. The caloric theory was finally overthrown by the labors of two men, Mayer and Joule, quite independently and neither having in the beginning any knowledge of the work of the other. Mayer, a Jewish physician of Heilbronn, began his process of reasoning with the observation that venous blood is a brighter red in tropical than in temperate climates. He was so ignorant of the terminology of physics that he could not make himself understood at first and suffered many rebuffs in consequence. His persistence however was sublime; he learned to write so that physicists could understand him, unearthed forgotten experiments, and eventually, without any experiments of his own, gave conclusive evidence for his theory and obtained a good value of the mechanical equivalent of heat. There could scarcely be a greater contrast than that between him and his fellow discoverer. Joule was a Manchester brewer and amateur of science, a skilful and accurate experimenter who

year after year turned out unimpeachable quantitative evidence of the equivalence between mechanical work and heat in all sorts of transformations. A third collaborator in placing the new theory on a firm foundation was Helmholtz whose celebrated memoir of 1847 showed clearly the generality of the new principle and its applicability to all branches of science; he gave it suitable mathematical formulation and demonstrated its great power in finding relations between phenomena of apparently different kinds.

The next step was the reconciliation of the new principle with that of Carnot, and it proved to be a difficult one. It puzzled Kelvin for several years and delayed his complete adherence to Joule's theory; ultimately he saw his way clearly and as a result of his work and that of Clausius the modern theory was established upon the two principles which stand side by side as the first and second laws of thermodynamics. These two empirical principles are probably the most firmly established and most thoroughly verified of all the so-called laws of nature. In the classical treatment of the subject they are regarded as axioms, and deductions are made from them so that, in form, the science is like geometry. As I have previously intimated, the results obtained are of great generality and of far-reaching consequence in practical applications as well as in philosophical implications. It is one of the great triumphs of theoretical physics.

Side by side with this theory there grew up another method of dealing with the subject which was less general and more hypothetical but has proved to be an invaluable aid to research. As soon as it was recognized that heat and mechanical energy are mutually convertible, it became inevitable that physicists should seek for a detailed mechanical theory of heat. The obvious hypothesis was that heat consisted of the energy of motion of the small particles, or molecules, of matter whose existence had been more or less generally accepted since Dalton's introduction of the atomic theory to account for the chemical laws of definite and multiple proportion. In order to develop this theory, the laws of mechanics had to be applied statistically to enormous aggregates of molecules reacting upon each other in various ways. The simplest state of matter from this point of view is the gaseous one; and in the hands of Clausius and Maxwell the kinetic theory of gases made great progress in a few years. Atomic and molecular theory became at once definite and quantitative. One of Dalton's atoms might be of any size so long as it was small enough to escape individual observation and had the correct ratio of mass to other atoms; but the atoms and molecules of the physical theory had definite and calculable mass, size, velocity and free-path. They became very real to physicists and were constantly used in reasoning and in planning experiments.

About twenty-five years ago a determined attack upon all atomic theories was made by Ostwald and his followers among the physical chemists—largely through ignorance of the real evidence upon which they were based. They ridiculed such theories as metaphysical figments of the imagination and attacked them as obstacles to real advance in the philosophy of nature. The faith of physicists however was not for a moment shaken; and it has been justified by the progress of discovery in the intervening years. The last doubting Thomas has been convinced and only those who deny the objectivity of matter itself can now question the real, physical existence of atoms and molecules.

Through the labors of Boltzmann, Gibbs and others, the application of statistical mechanics to molecular problems was developed and generalized so as to be applicable to other states of matter than the gaseous one; and attempts were made to reduce the whole of thermodynamics to a mechanical basis. The subject is a very difficult one with many pitfalls for even the most wary; and we must conclude, I think, that the attempt has met with a defeat that is probably final. It has, however, led directly to the quantum theory of Planck, a great generalization which is the most puzzling and the most promising treasure in the possession of the physicist of today.

The next great landmark of which we must take note is the unification of the theories of electrodynamics and of optics by Clerk Maxwell. He himself tells us that, impressed by the value and fertility of Faraday's ideas, he decided, in beginning his serious study of electricity, to read no mathematics on the subject until he had mastered Faraday's "Experimental Researches." Maxwell was a highly trained and original mathematician and his first papers on electrodynamics were devoted to the expression in clear mathematical form of some of Faraday's hypotheses and modes of thought. Like his chosen master he rejected action at a distance and concentrated his attention upon the hypothetical medium by means of which electromagnetic forces might be transmitted. In several memoirs published during the sixties he gave details of mechanical models which were adapted to this end. By gradual steps these auxiliaries were done away with and at the same time the theory far outgrew its original purpose of translating Faraday into mathematical language. Maxwell showed clearly that all the known facts of electrodynamics could be attributed to the action of a medium and by strict mathematical reasoning he deducted the properties which this medium must have. These turned out to be identical in all details with those which we must attribute to the luminiferious ether in order to account for the phenomena of light. Thus was born the electromagnetic theory of light and two great domains of physics were brought together under a single system of hypotheses clearly expressed in the form of differential equations.

The publication of Maxwell's "Treatise on Electricity and Magnetism" in 1873 was an event of the first importance in the history of science. The new theory was slow in making its way, especially on the continent of Europe, and Maxwell himself died in 1879. His work was taken up, however, by a group of devoted adherents among whom we may mention Heaviside, Lodge, Rowland, Poynting, Gibbs, J. J. Thomson, and Larmor. In 1886 Hertz, whose attention had been some years before directed to Maxwell's theory by Helmholtz, made an accidental observation which to his acute mind offered the possibility of a direct test of the finite speed of propagation of electromagnetic action. His brilliant series of experiments demonstrated the existence, speed, and properties of electromagnetic waves and served as a complete verification of Maxwell's theory. All of you know that the wonders of wireless are a direct consequence of the experiments of Hertz; but to the physicist this is less interesting and significant than the steady growth in scope and authority of Maxwell's equations, which come nearer to the ideal of a "world formula" than anything else known to the modern man of science.

For something like ten years it was generally supposed that the main outlines of the science of physics had been drawn in fairly satisfactory, and perhaps final, form. There was still much to be done but it would be concerned with details—with perfecting theories and increasing the accuracy of measurements. A great deal of very valuable work of this kind was done in many fields; as an example I may refer briefly to the development of accurate measurement in spectroscopy.

The use of the spectroscope as a method of chemical analysis was placed on a sound basis about 1860, by Bunsen and Kirchhoff, and the application of this method was extended, by the brilliant discovery of Kirchhoff, to the atmospheres of the sun and stars. You all know something of the wonderful results which have followed the application of the spectroscope to astronomical problems and of the growth of the borderland science which is called astrophysics. Great improvements in spectroscopic apparatus were made by Rowland, Michelson, and others, and there grew up a body of skilful spectroscopists, who devoted themselves to the accurate measurement of the wave lengths of the innumerable spectral lines given out by the different chemical elements and to the discovery of empirical relations between the numerical values of these wave lengths. It was hoped that such observations would throw light upon the structure of atoms but for many years no progress was made in this direction. Indeed it is only recently that the results of a generation of spectroscopists are beginning to be useful for this purpose and only after the clue to a theory of atomic structure had been given by investigations in other fields. Spectroscopy is almost the only part of physics in which a

large mass of data was accumulated before the existence of a guiding hypothesis or theory to direct the work. The method of simple induction and classification which has played so large a part in some other sciences seems to be unsuited to the problems of physics.

Accurate measurements, however, do sometimes produce brilliant discoveries—when they fall into the right hands. A classical example of this is the discovery of argon by Lord Rayleigh as the result of a quite prosaic undertaking to redetermine with great accuracy the density of nitrogen. As a sequel to Rayleigh's work, a whole family of chemical elements, whose existence had been entirely unsuspected by chemists, was discovered by Ramsay. But it is only in rare instances that this sort of thing occurs; usually an accurate measurement leads to no exciting result, but takes its place among the solid foundation stones of the science. And for perhaps a decade there was fairly widespread opinion among physicists that this was what they must look forward to, and that the future of physics lay "in the last place of decimals."

These anticipations of a useful, if somewhat dull, old age for the science were happily disappointed in the last years of the century by the remarkable outburst of unexpected discoveries among which the Röntgen rays came first in point of time. This was followed almost at once by Becquerel's discovery of radioactivity, the identification of the subatomic "corpuscle" or electron by J. J. Thomson, and the investigations of the ionization of gases which have led to many important result. No physicist who has reached middle age can forget the romantic interest of the ten years following 1895, when startling discoveries followed each other in rapid succession and the physical journals were awaited with an impatience not unlike the desire for newspapers in wartime. But the news was all good news, and recorded an almost unbroken series of victories.

These discoveries were, as I have said, unexpected but they were not in any real sense accidental. They came as the result of a careful and prolonged study of the electrical discharge through rarefied gases—a complicated set of phenomena very difficult to put in order. Twenty years earlier, Maxwell had predicted that the next great step in our knowledge of the relations between electricity and matter would come from a study of the discharge through gases; and it had been prosecuted in that spirit by many men though the clue which they sought eluded them for twenty years. When it did come at last, it was in a form which was, so far as I know, entirely unpredicted and unexpected. This was so much the case that it took us more than fifteen years to find out quite certainly just what the X-rays were. It was not until 1912 that Laue's discovery of the diffraction of X-rays by crystals and the subsequent work of W. H. and W. L. Bragg made it quite certain that these

rays were of the same nature as light but with wave lengths only about 1/5000 of those in the visible spectrum. This had indeed been for some time the prevailing hypothesis as to their nature but there was little quantitative evidence to support it; and only a year or two previous to the discovery of crystalline diffraction W. H. Bragg himself had brought forward many reasons for thinking that X-rays might be corpuscular. The study of these very short waves has already given us invaluable knowledge of the nature of the atoms of different elements and promises still greater advances in the future; it has provided a new and powerful method of studying crystal structure and has revolutionized our conception of the nature of chemical combination in crystalline bodies; and it promises to have practical applications as useful in industry as ordinary spectroscopy.

The discovery of the radioactivity by Becquerel followed almost immediately upon Röntgen's discovery of the X-rays, and was in a sense a direct consequence of it; they are alike too in that they have both had important medical applications which have drawn much public attention. Madame Curie's sensational discovery of radium was an early incident in the history of this subject. But by far the most important development in this field was the establishment by Rutherford and his pupils of the cause and source of energy of these radiations. He has shown in the most conclusive way that they are due to the disintegration of the atoms of the radioactive elements—uranium, thorium, radium, etc—and that a spontaneous transmutation of these elements is going on constantly. The genealogy of the radioactive elements is known more accurately than that of most royal families; and the birth and mortality statistics of the various kinds of atoms are in all the text books. Thus a part of the dream of the alchemists has come true, but only a part; for up to the present all attempts to produce artificially the transmutation of the heavy elements have failed. In fact we have not been able to affect in the slightest way the spontaneous transmutation of the radioactive elements; it can neither be retarded nor accelerated by any agency at our command. We do know, however, that vast stores of energy are locked up in the atoms of the heavier elements and if the time should ever come when this can be released and controlled by man it will doubtless cause a revolution in industrial processes more fundamental than that which followed upon the introduction of steam and electricity. One small step in this direction has been taken within the past two years. Rutherford has obtained evidence that the nitrogen atom may be broken up by bombardment with alpha rays, and that one of the products of this process is hydrogen. It is perhaps too early to regard this as being definitely established; and, even if it be true, the amount of matter transmuted in this way is excessively minute while the quantity of energy released in the process (if any) is far be-

low what could possibly be measured experimentally. We have however become accustomed to small beginnings which ultimately produce great results; and a modern physicist would be rash indeed who should attempt to set bounds to the possibilities of future discovery in this direction.

The discovery of the electron was also an event of the first importance in the history of our science. It is the ultimate atom of negative electricity and is a constituent of all material atoms. It can also exist in the free or "disembodied" state, as for example in the cathode rays, the beta rays from radium, and in the electronic stream from incandescent bodies. In the last of these forms it has proved to be of great practical use to telephony and wireless telegraphy in the audion or thermionic tube which is the cause of most of the remarkable advances in these fields during the past five or six years. To the physicst and chemist of today the electron is an indispensable concept in both theoretical and experimental investigations; and its reality can be questioned only on those philosophical grounds which may put in doubt the existence of matter itself.

The nature of positive electricity is not so definitely known; but evidence is accumulating that it too exists in an atomic form as the "nucleus" of the atom of hydrogen—the residue left when the hydrogen atom is deprived of its single negative electron. It is becoming probable that the "nuclei" of other atoms are built up out of these and of negative electrons. If this group of hypotheses should stand the test of time we shall have to conclude that matter and electricity are different aspects of the same stuff—that the atoms of matter are formed by different collocations of the atoms of positive and negative electricity.

Another line of physical inquiry which has proved to be of deep and fundamental significance is the so-called quantum theory of Planck. It originated in the study (both experimental and theoretical) of the intensity and quality of the radiation from a "black body," or perfect radiator, when held at a definite temperature. The total intensity of such radiations were deduced theoretically by Stefan from the principles of thermodynamics and the predicted results have been amply verified by experiment. When however the attempt is made to predict the way in which the energy is distributed in the spectrum, so as to be able to tell what fraction of the total intensity is carried by any particular wave length, the problem becomes much more difficult. It is necessary to have recourse to statistical methods analogous to those used by Maxwell, Boltzmann and Gibbs in accounting for the thermodynamic properties of material bodies. First steps in this direction were taken by W. Wien but the deductions from his theory were not altogether in accord with experimental results. Planck succeeded in ob-

taining a formula which agreed with experiment, but only by making certain very daring hypotheses; the most conspicuous of these is that the emission, or the absorption of radiation, or both, takes place not steadily and continuously as we had always supposed but by finite, discrete "quanta." From one point of view this hypothesis of Planck may be regarded as extending the field of the atomic theory, hitherto restricted to matter, to energy as well. I can not hope to suggest even remotely in the brief time at my disposal how revolutionary Planck's assumptions really are; they are still very imperfectly understood and it has not yet been possible to reconcile them wholly with other facts and general laws which appear to rest upon very solid foundations. Indeed, if the results of Planck's speculations had been confined to the deduction of a formula for the radiation of a black body they would not, I think, have long engaged the serious attention of physicists. But they began to turn up unmistakably in many other fields of investigation—for example, in connection with the photo-electric effect, with X-rays, and in all theories of atomic structure. At present no one doubts that most of our fundamental ideas in mechanics and electrodynamics must be revised in the light of the quantum theory which however is itself still in a very immature state. The problem thus arising of bringing together under one system apparently discrepant bodies of phenomena is an exceedingly difficult one and we may have to wait for another Newton to solve it. But it possesses the greatest fascination for all theoretical physicists; they are able to congratulate themselves upon the possession of an unsolved problem of the first magnitude and of great difficulty and they know that as long as it lasts, life will not be dull for them.

I should be in despair if it were necessary to give, at the end of a lecture already too long, an account of Einstein, relativity and gravitation. Fortunately any need that you may feel for instruction on these subjects has doubtless been satisfied by the newspapers, the magazines, and by innumerable books, popular and otherwise. Let me say in all seriousness however, that the more one knows of the history and recent developments of physics the more sincere and ardent is one's admiration for the individuality and brilliant originality of Einstein's genius. It does not seem probable at present that his discoveries will have as great an effect upon the immediate future of physics as some of the others which I have just discussed. But the ultimate result of his work upon *methods* used in the theoretical side of physical science may well prove to be revolutionary; and it seems highly probable that it will change to some extent our philosophical views of the nature of the external world and of our relation to it.

It may have occurred to you that, in my hurried sketch of the progress of physics since 1895, I have made very frequent use of such

terms as "important," "epoch-making," or "revolutionary." The truth is that all the various discoveries and theories which arose more or less independently and have been separately mentioned are constituent parts of one "revolution" which has not yet reached its climax. It is one of the greatest intellectual pleasures of the present day physicist to see how all these apparently diverse things are fitting into each other and taking their appropriate places in a general scheme which is rapidly assuming form and coherence. The new ideas in physics are having a profound influence upon the fundamental theories of chemistry and are bringing the philosophies of the two sciences much closer together. They have already made possible a rational theory of the periodic law of Mendelejeff, and have displaced the atomic weight as the controlling factor in the determination of the chemical properties of the elements. They have also given grounds for a very reasonable hope that the near future may see the development of a real theory of chemical combination, which is certainly much to be desired.

The general character of the profound change which is taking place in the fundamental ideas of both sciences may perhaps be stated briefly and inadequately in the following terms. The recent discoveries in physics have enabled us to experiment in several ways with the individual atom and to find out something of its properties and activities. Until recently we have been able to deal only with statistical averages of the behavior of vast numbers of atoms and molecules and all of our physical laws have been based upon such statistical knowledge. The apparent discrepancies between the older and the newer formulations may well be due to this difference. It is quite possible that the ultimate laws which govern the actions of atoms are quite different from the laws of mechanics and electrodynamics which are so familiar that they seem almost axiomatic. If this should be so, the familiar "laws" will in no way lose their validity within the field that they have ruled so long; but we shall know that they are not fundamental and primary, but secondary statistical laws in which much of the individuality of physical activities has been ironed out by the process of averaging. To come to this point of view is of course rather a wrench for those of us who have been nursed and reared in the old régime. But this discomfort is much more than compensated for by the fascinating and apparently inexhaustible field for research and speculation which is now being opened up for our use and pleasure.

PERIODICAL CICADAS IN BALTIMORE, MD.

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IN the northern parts of Baltimore as now extended to include fields and woods certain restricted areas long inhabited and well grown with shade and fruit trees about country and suburban residences were overrun with great numbers of the noisy and conspicuous periodical cicada, Cicada septendecim, popularly known as the seventeen-year locust, during the early summer of 1919 and the same was true in even greater force in 1902 as I have observed.

Upon digging into the earth under sod or in old plantations of shrubs and trees in 1916-'17-'18 one saw many tunnels or tubular holes smaller than one's finger, but many inches long, two feet or more under the surface and in each might be a clumsy light colored gnome-like creature with grotesquely large and powerful front legs and claws and provided with an enigmatically closed-in face and head, making it a matter of search to discover the concealed tube or sucking mouth—apparatus through which it had been many years drawing from the roots of trees and shrubs the juices that had enabled it to grow to the size and plumpness of a peanut (with some of like food value). These cicada young in the spring of 1918 pushed their tunnels up well toward the surface of the ground and led one to surmise that they might be about to emerge from the dark into the air above. In fact some few must have done so for later in the summer a very few were heard singing their unmistakable song in the trees and a few of their cast off pupal cases were collected at the foot of trees, smaller than the seldom found cases of the non-periodical cicada, or harvest fly, Cicada tibicem.

But in 1919 the holes in the ground were all extended up almost to the surface or even beyond, as described below, and finally after seventeen years of darkness each inhabitant emerged from its own tunnel into the dim light of late day to transform into the winged insect.

Excepting as below noted these tunnels present the mystery of no seeming place for discharge of the excavated soil: but Fabre has given a remarkable suggestion as to how the tunnels may be made in dense soil with no outlet for soil removal.

In April and May diggings under apple trees showed very many vertical tunnels, each straight and smooth lined, each ending very near the surface with a well made roof of earth hollowed out below as dome over the vertical burrow. In each sat one larva braced with its

legs against the smooth sides but ready upon slight disturbance to shut up its legs and drop down to the moist bottom of the tunnel if not given time to slowly crawl down into safety. When the top was dug off from the tunnel the inhabitant soon fashioned a new arched roof at the top.

Where boards lay on the ground the holes that came up under these obstacles were prolonged out of the earth against the board and then turning at right angles extended many inches horizontally along under the board as circular passages with walls made up of small pellets stuck together and all smoothed off inside. Often the board itself furnished some part of the roof of these horizontal extensions of the burrow.

Is it the light or heat that is sensed in the vertical burrow to bring about a cessation of work when near the surface, and is it the absence of this contrast between deep down and near surface which leads the larva under the board to keep on and on where possible and so to impress upon the onlooker the idea that the larva is aware of the obstacle to emergence?

Very many such restrained larvae remained under the boards after those in the open had emerged, but finally most of those under the boards found a way to the edges and escaped. When such board was raised the larvae were often in the horizontal burrows and could be more readily caught as they ran but slowly along to the vertical burrow down which they went with speed so great that rapid cut off from below with knife or spade was the only chance of intercepting their flight.

In some regions, chiefly those well shaded or not with normal exposure to light and air the vertical tunnels rose up into the air in the form of a chimney closely resembling those made by burrowing crayfish. Each chimney is built up by additions of small pellets of mud brought from below, often of the hard subsoil or clay and hence conspicuous upon the darker top soil. Each may be one and a half to two inches or more in diameter and one to five inches in height and either straight vertical or bending to one side.

In any case when not being worked at, each chimney is capped over at summit completely by pellets that make the top like the sides all one mass of irregular roughened drying or dry mud easily kicked aside as of no importance, yet each chimney upon being broken from its continuation down into the earth is seen to have in it the same vertical tunnel as large as one's finger, nicely smoothed on all its walls and arched over at the top by the smooth dome that is present at the top of all the vertical burrows which stop short of reaching the surface of the ground.

Such chimneys arose in great numbers in a small garage shed,

closed in and dark. They were found under a porch beneath which roots of Norway maple extended and where light was very dim. These little chimneys in great numbers stuck up in the tall grass close to the bases of trees, around the bottoms of cherry trees along a privet hedge, and under the hedge itself where the shadow is always deep. When knocked off they lay about like so many mud finger stalls.

The numbers of holes varied greatly but in many places there were ten in a square foot; yet all garden or flower bed soil contained none and the same was true of roads and paths even though the roots of the trees extended under them and the gravel might have permitted egress.

Observations upon such cicada pupae kept in jars of earth in 1902 showed that the peculiar face of the insect was used as a hod to bring up to the surface of the ground the small pellets of mud collected below and laboriously carried to the surface. As the tunnel making involves no transport of material, it is the more enigmatical that the chimneys and horizontal tubes under the boards are made by hard work of a kind not, apparently, known during the 17 years of underground life.

The earliest date recorded for the coming of these cicadas forth from the ground in Baltimore was the finding May 16 by Mr. Ibara of one male with expanded wings in Druid Hill Park and one male in Wyman Park. While at the same date I observed the wings of one individual on a flower bed in my garden, apparently an early pioneer that had been sacrificed to the eager birds.

On the 21st of May a pint or more of winged forms were recorded as collected on the south side of Professor Mast's house in Roland Park. On the following day I saw the first pupae emerging and going toward the trees in my lawn while many persons reported them as appearing in numbers in Govans and Mt. Washington. On May 23 there was a second emergence from eight to nine p. m. when there was still good daylight. Many reports stated that the cicadas were emerging at Embla Park and on Charles Street north of Homewood, in great numbers. On May 24 the cicadas emerged again before 8 p. m. and walked straight toward the trees.

From then on cicadas came out of the ground every evening from eight to ten p. m. and some few later in the evening but the numbers emerging in any one region fell off till very few indeed came out after the first of June. May 26 many emerged as early as 7:30. In general the emergence began earliest in the season in localities that had the warmer soil and later in cold clay or in regions on north of buildings. Localities a few hundred feet apart differed by 7 days in date of first emergence. But even in the latest region, under trees north of house the few last cicadas were coming out June 7th and no more came out June 8th. Thus the entire outburst from the ground life of seventeen years was concentrated within a maximum of three weeks time while

in any one spot the emergence was restricted to a period of less than two weeks.

Having lived some seventeen years below ground, the first advent into the air is followed by a remarkable migration before the actual hatching out of the larva-like pupa into the imago or perfected winged insect.

Upon breaking slowly through the arched dome that ends its vertical burrow, the pupa thrusts its head into the air above while there is still daylight of rapidly diminishing intensity and seems to face in various directions before actually coming out of the burrow. But once upon the earth the pupa begins a most persistent rectilinear journey toward some neighboring object, tree, wall, grass or flower stalk, or building. Standing under an isolated tree, it is a remarkable sight that presents itself when from north, south, east and west and all intermediate radii the emerging pupae, as if all of one mind march steadily toward the tree trunk at the center of their entire area of emergence.

Arrived at the tree or other upright they do not hesitate to climb up it with slow but steady progress often for many feet of vertical toil, but when a horizontal outlying part, as a branch, is reached, the pupae turn aside from the vertical which they had so long persisted to maintain underground and again resort to the horizontal journey they had recently quitted when ascending from the earth to the tree trunk. Out toward the ends of the branch they climb upon the twigs and the leaves and there finally come to their journey's end. Here they stretch out their legs, so that the hooks on their ends firmly hold them and as darkness comes on the transformation is completed; each back splitting open to allow of the slow emergence of a conspicuous white and very soft creature which will hang head down in apparent danger of falling to the ground till strong enough to mount upon its shell, gain a firm footing, and slowly pump up its wing pads with air while allowing of the fermentative processes in its soft skin to fashion a dark and stiff encasing layer that will make it henceforth so well able to use its muscles and be protected from minor injuries. As the eyes color red and two squarish areas above the wing muscles early turn black, the generally yellow white of the hatching adult is the more striking.

The next morning few indeed remain in such undefended softness since with the coming of day most all of the night's product vibrate their wings and fly away with great speed and strength of flight, well able to elude many birds on the wing and as well able to dodge about the limb or take again to wing when in danger of attack.

The three stages of the first journey in the above-ground were strikingly shown in the case of many cicadas arising from the earth near clothes poles which they found after a horizontal walk of many feet

and mounted vertically five feet then to crawl out horizontally along the slightly sagging line only $\frac{3}{16}$ of an inch thick to settle down and transform all along the line up to a maximum distance from the pole of forty-eight feet.

Concerning the first part of the journey above ground, the walk to the trees, two sets of observations suggest problems to be solved, as to orientation with reference to vertical objects. The first observations relate to the numbers going to one isolated tree; the others relate to the distances traversed as if impelled by the sight of that tree.

Having in advance of the emergence protected most trees by bands of tin about the trunk it was found that the cicadas could not climb up this smooth surface, unless some crack allowed of use of the front leg nippers, and thus as fast as they arrived at base of a tree they tended to accumulate there and were not rapidly dispersed up over the whole tree where they could not be counted, while by collecting the cicadas arrested by the tin barrier a fair estimate of the entire number arriving at any particular tree could be readily had.

The tree most observed was a very large pear, probably Doyenne Boussock, thirty feet high by actual measurement and with a spread of twenty-one feet; its branches were nine feet above ground at origin but sagged somewhat and were very dense so that the tree was a very dark object; the overhang of the limbs toward the south was about eleven as opposed to ten feet toward the north. This tree stood isolated on a cut lawn, fourteen feet from a privet hedge running East and West, five feet high and six wide and was 36 feet from a silver maple toward the southwest, twenty-five feet from a very feeble old pear tree of 12 feet height and 10 feet spread to the north and 22 feet from a cherry tree in hedge to North East having spread of 10 feet and height of 17 but like the old pear tree casting little shade. The trunk of the big pear tree was 3 feet 9 inches in circumference at base.

The cicadas which emerged from the ground under this big pear tree, went toward the trunk as if drawn by a powerful magnet, both from near the hedge and from all other radial directions, but meanwhile some few cicadas under the hedge and under the other trees above mentioned remained in their own areas of attraction and climbed up the hedge plants or strove to ascend the tree trunks. However, it was evident that the big pear tree drew the great majority of all cicadas emerging within a circle much greater than its branches overhung and absolutely controlled all cicadas emerging under its branches.

The following figures show the run of cicadas collected at the base of this big pear tree daily, evening and morning May 22 to June 3. Those collected in the evening represented most of those of the day but as a few came out late these were collected in the morning and added to the previous evenings count for the total of that day. Thus on

the 26th, 550 were taken at 8:30 and 250 more at 11 p. m. and 110 were waiting at the tin the next morning at 9.

Numbers showing daily emerging of 4,983 cicada pupae from area 15 feet radius around one tree during thirteen days, May 22 to June 3 inclusive; 65, 240, 400, 338, 910, 784, 551, 738, 561, 234, 118, 39, 5.

That is, the first day saw only 65 emerge, but the second day 240 and so on till after a maximum of 910 on the fifth day, there was a slow falling off and then rapid decline on the last three days from 118 to only 5.

In like manner, other trees yielded daily crops of cicadas from their roots and these newly emerged parasites strove to attain the trunks and branches near at hand. Very large numbers were involved in small areas. In two weeks one hundred quarts of cicadas were gathered by hand from about one acre of ground while in addition probably as many more were consumed by Indian Runner ducks let loose morning and evening for the purpose of eating up the emerging cicadas, which they accomplished to the limit of capacity of each individual crop and with the greatest enthusiasm and persistence.

As it was found that one quart of winged cicadas contained from 270 to 330 individuals and weighed 10½ to 12½ ounces and that a quart of the emerging pupae contained 435 crawling individuals with weight of 17 ounces, it is evident that the entire number emerging from an acre of such suburban land runs up toward one hundred thousand with a combined weight of near one-tenth of a ton.

Turning to the second set of observations that relate to the possible modes by which the emerging pupae are able to find a tree to climb.

At the Northeast corner of a large lawn bounded North and East by hedges at right angles stood a black locust tree fifty or sixty feet in height at the end of a row of like trees running East.

It was found that the root system of this tree extended under the sod to a distance of at least seventy feet. Over this area the cicadas emerged in numbers and crawled toward the tree trunk along radii all over the quadrant represented by the area between the above hedges.

One cicada was watched from a point 61 feet from the locust tree as it went straight toward the locust tree although behind it on the same radius stood a smaller pear tree twenty-four feet away with height of some 18 feet. The large locust tree had few branches till toward the top and appeared as distinct area of but light foliage against the sky at the time of evening when the cicadas were emerging. Another cicada started from a point nearly in the center of the entire area, 36 feet from the locust tree. And a third from 27 feet though behind it was a small pear tree only four feet away. Standing on the lawn it was astonishing to see so many cicadas walking along all possible

radii from such distances as if drawn to the trunk; while many moved along parallel to the hedges and turned not aside others went along all the radii between these two hedge radii that were at right angles to one another.

A great many cicadas emerged every evening, as May 22 and 23, and all marching toward the exact middle of the tree they became concentrated more and more as they drew near the tree. However, it happened that scarcely one of this host ever reached the tree, for while but five or six out of hundreds turned aside to mount up the privet hedge some six feet in height and width, the great majority after the long walk met with an obstacle in the shape of a chicken-net wire and tall flowering orchard grass some seven or eight feet in extent and one and a half wide lying across the line of march and but five feet from the trunk of the tree. Coming to these upright but slender grass stalks the cicadas all mounted up and there stretched out to transform. Some successfully transformed though most were collected when so easy of access.

The impression made by so many individuals on different days all centered toward the same object was of forced movements impelled by the tree's presence, but whether the cicadas moved thus radially on account of their life underground having been often radial along the root system or whether for the first time the tree appealed to them as being in some sense seen against the sky was not evident. When such crawling cicadas were interrupted they returned again to their radial course.

As bearing upon the use of the eyes in this orientation may be cited a few experiments made in the midst of the lawn: a kitchen table was placed radially and cicadas placed upon it with the result that the cicadas continued along the radius toward the tree till coming to the end of the table they fell off and resumed progress in the same direction on the grass. When reversed on the table they generally soon turned back into the direction toward the tree. When both eyes were blackened with asphaltum the cicadas wandered about on the table or on the grass not showing any distinct orientation. A few with but one eye blackened seemed to walk toward the tree without much hesitation, but these experiments were made too late in the evening to be well observed.

In general one was left wondering if the cicadas did not actually see the tree in some way and be influenced by it as if it were to them a conspicuous elevated area.

For a few days after emergence no noise came from the winged cicadas but on May 26th they were very plainly heard along Charles street road and on Cold Spring lane and on the 28th along Bellona Avenue and in the woods of Homewood.

From then on all day their peculiar cries resounded in and near all other regions of emergence while very many silent areas showed their absence. While at first heard only in the heat of the day, by May 31st when the temperature had risen to 89° and the air was dry their unwelcome noise lasted on late into the night and on the leaves of trees some were found pairing.

They continued noisy day and even at night, June 6, but then more and more showed the destructive fungus in their bodies. One last noisy one was heard June 28 after a week of near silence.

It was not this species of Cicada of which the poet sung:

> Du kluges Kind der Erden,
> Du Freundin schoener Lieder,
> Wirst nie from Alter traurig.
> Dich plagen keine Schmertzen,
> Du hast, so wie die Goetter,
> Kein Fleisch und kein Gebleute,
> Bist du nicht ihres Gleichen?

During the period of mating the cicadas collected in great numbers upon trees and bushes often at considerable heights and too frequently upon trees remote from those under which they had emerged so that despite decimation from collecting, fresh flying insects from neighbors' trees again populated the partially cleaned area; but there was no evidence of any wide migration so that concerted action could readily have rid infected areas of a large part of the accumulations of seventeen years' growth. Not only was the tin placed about trees good protection when combined with collecting by hand or by duck aid, since it arrested the crawlers and held them restricted till the daylight made collecting easy; but later on when the trees were full of flying insects the tins still had useful features. Thus June 7th after a thunder storm many flying insects were beaten to the ground and under the above pear tree 150 were found struggling to climb up the trunk and held back by the tin since they preferred the old way of crawling and climbing to get to an elevation from which to take wing. In this connection may be noted that when a tree was shaken, while most flew away many pairing or separate fell to the ground and thus could be caught: June 4th at 8 p. m. 282 were thus gathered under the pear tree.

Upon the trees the cicadas tended to congregate upon the warm sunny aspects and to crowd upon certain outstanding branches or twigs, flying constantly from twig to twig as if in search of something and gradually aggregating upon certain favored trees though neglecting completely very few indeed.

By June 3 the females were rapidly laying eggs in the twigs of ash-leaved maple, apple, plum, peach, apricot, pear, etc.

By June 8 no more were emerging. June 17, many were dying, and before the end of that month practically all adults had ceased to exist.

Meantime the new generation was progressing. As is well known the fecundated female chooses top and outlying twigs for deposit of her eggs and walking along saws into the wood deep gashes in regular series within which the same efficient ovispositor that rips open the wood deposits nicely placed packets of elongated eggs.

So deep are these injuries to the twigs and so extensive the areas affected that many twigs fail to carry their usual sap and hence the leaves shrivel. By June 17th many trees showed so many terminal twigs with brown and shrivelled leaves that it seem as if they had been scorched by fire. By June 29th the rain and wind had broken off many of these too deeply injured twigs and strewn them on the ground. Such twigs taken into the dry laboratory showed after a week only dried and shrivelled eggs, so that it may well be that very many eggs perish when the twigs in which they are placed are so severely injured that the twigs fall off. On the other hand, the great majority of twigs were not so severely injured as to loose vitality, and these remaining upon the tree finally liberated the young. Such twigs cut off and placed in a jar of water and thus kept from too great drying yielded large numbers of the young.

From August 8 to 23 such stems taken indoors yielded large crops of small white larvae which coming out of the wood crawled along and soon fell off. When the water jar was placed in a large bowl the young falling off were unable to escape up the smooth sides and gradually collected in large numbers and could be removed before they dried up.

Unlike the pupae, which emerging into the light leave a darker for a lighter region, these newly hatched larvae go from the light towards the darker areas and so collect underneath overhanging objects. Unlike the pupae which strongly strive to crawl upward the newly hatched larvae tend to crawl downward.

When placed upon earth these little larvae soon managed to dig in and disappeared from the light downward into the dark earth.

Mr. Ibara found that such young in receptacles with grass attached themselves to the roots of the grass and apparently began thus to feed from the juices of these plants.

Amongst so many cicadas coming under observation there were notable diversities. Not only the well-known dwarf cicadas, but certain exceptional varieties were observed. The dwarfs often emerged in large numbers largely by themselves with few of the larger forms at the same time and place and were especially common under a very old russet apple tree.

Amongst 9½ quarts of the flying cicadas gathered June and chiefly perfected the night previous, there were two with white eyes, one with black eyes and one with chestnut brown face. The white-

eyed cicadas have also lighter colored costal edges to the front wings and this might be considered a failure to completely darken the wing which at first was white and normally turns darker soon after hatching out from the pupa case. The white eye, however, is of fundamental nature since the normal red eye is one of the earliest areas of the body which stands out against the general whiteness as fiery red and in these two white-eyed individuals the absence of color in the eye dated back beyond the time of transformation.

Thus amidst about five thousand seven hundred cicadas two had white, one black and one chestnut colored eyes. Other collections showed that white-eyed and brown-eyed forms occurred now and then both in this same region and in Roland Park and thus from diverse groups that had been separated a couple of miles for seventeen years at least.

In the assumedly rather uniform and simple conditions of seventeen years of growth under ground there would seem little opportunity for light or other external conditions to exert any such modifying influence as might lead to white in place of red eye. Regarding the two periods of life, the short one as active larva getting into the ground and the concealed egg in the wood, as opposed to the germ life in the active adult, we seem safe in assuming that here as elsewhere the initiative to change in eye color came in the germinal material.

The injury done to trees and shrubs by the adult females in laying is not only the immediate death of important twigs when too severely cut by the ovispositor but in the leaving of wounds that may later cause injury. While the severely injured twigs may fall off soon and thus often lead to the failure of the cicada eggs from drying, the partly injured twig remains and begins to heal over, but this overgrowth rarely overtakes the young before it comes out of the wound. The following summer, 1920, many of the injured twigs were healed over more or less completely. Nevertheless the wood had been so deeply injured that a great many twigs bearing green leaves and such fruits as those of the Norway Maple were wrenched off by storms owing to the internal weakening caused by the previous season by the cicadas.

While the extensive pruning may not cause serious results in many shade trees, the dying off of twigs, the remaining of dead tips and the presence of innumerable wounds is of moment in some fruit trees and in the dogwood the pruning back by the cicadas tended to make considerable changes in fruiting, flowering and proportions of growth, while in some chestnut shoots recovering from dying down after the blight the wounds made by cicadas were placed with reference to new infestations of the blight so as to suggest that the blight had entered through these wounds in the firm young bark.

How serious the loss of sap of roots through long years of cicada sucking may be, remains to be found out.

The almost absolute completeness of the emergence in 1919 is seen in the fact that in 1920 search for these seventeen year locust yielded not one. Even in the region along Charles Street north of University Parkway where in 1919 the cicadas were swept up from the sidewalk in great numbers no cast off shells could be found in 1920 and but one solitary song in this region indicated that there had been an emergence of one of the race this season; all the others having come out in 1919 with practically no lag.

It is the phenomenal uniformity with which all these creatures in a given region run through their long period of growth to emerge within so few days after seventeen years and with so few exceptional hurried or lagging individuals that presents a problem in rhythmic growth of great interest as is also the question as to how far these insects may be guided by sight in the first use of their eyes upon coming from seventeen years of apparent darkness. These and other questions may be approached experimentally if attention is called to this field in time; and fortunately some broods of these insects come out at predictable dates in various parts of the country in different years so that observation can be spread over much of the long interval otherwise lost in any one locality.

THE BIOLOGY OF DEATH. II—CONDITIONS OF CELLULAR IMMORTALITY[1]

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1. Artificial Parthenogenesis

IN the preceding paper in this series it was pointed out that the germ cells of higher organisms are potentially, and under certain conditions in fact, immortal. What are the conditions of immortality in this case? Are they such as to support the thesis that the processes of mortality are essentially physico-chemical in nature, and follow physico-chemical laws?

The most essential condition of this immortality of germ cells was mentioned, but not particularly emphasized. It is that two germ cells, an ovum and a spermatozoon *unite*, the process of union being called fertilization. Having united, if they then find themselves in appropriate environmental conditions, development goes on, new germ cells and a soma are formed, and the same process keeps up generation after generation. Now while union of the germ cells is generally and in most organisms an essential condition of this process, it is also true that in a few forms of animal life, mostly found among the invertebrates, development of the ovum can take place without any preceding fertilization by a spermatozoon. The process of reproduction in this case is called *parthenogenesis*. In a number of forms in which parthenogenesis never occurs normally, so far as is known, it can be induced by appropriate extraneous procedures. The discovery of this extraordinarily interesting and important fact for a number of organisms, and the careful working out of its physico-chemical basis, we owe to Dr. Jacques Loeb, of the Rockefeller Institute for Medical Research. Artificial parthenogenesis may be induced, as Guyer, Bataillon and Loeb have shown in so highly organized a creature even as the frog, and the animal may grow to full size. The frogs shown in Figure 1, while they present much the same appearance as any other frog of the same species, differ in the rather fundamentally important respect that they had no father.

The rôle of a father was played in these cases by an ordinary dissecting needle. Unfertilized eggs from a virgin female were gently pricked on the surface with a sharply pointed needle. This initiation

[1]Papers from the Department of Biometry and Vital Statistics, School of Hygiene and Public Health, Johns Hopkins University, No. 20.

FIG. 1. ARTIFICIALLY PARTHENOGENETIC FROGS. (Loeb.)

of the process of development took place March 16, 1916, in one case, and February 27, 1917 in the other. The date of death was in the first case May 22, 1917 and in the other March 24, 1918.

In the course of Loeb's studies of parthenogenesis in lower marine invertebrates, he became interested in the question of the death of the germ cells which had failed to unite, or having united failed of appropriate environmental conditions. His researches throw light on some of the conditions of cellular death, and on that account they may be reviewed briefly here. He found that the unfertilized mature eggs of the sea-urchin die comparatively soon when deposited in sea-water. The same eggs, however, live much longer, and will if appropriate surrounding conditions are provided go on and develop an adult organism, if they are caused to develop artificially by chemical means or naturally by fertilization. Loeb concluded from this that there are two processes going on in the egg. He maintained, on the one hand, that there are specific processes leading to death and disintegration, and, on the other hand, processes which lead to cell division and further development. The latter processes may be regarded as inhibiting or modifying the mortal process. Loeb and Lewis undertook experiments based upon this view to see whether it would be possible by chemical treatment of the egg to prolong its life. Since in general specific life phenomena are perhaps on the chemical side chiefly catalytic phenomena, it was held to be reasonable that if some substance could be brought to act on the egg, which would inhibit such phenomena without permanently altering the constitution of the living material the life of the cell should be considerably prolonged. The first agent chosen for trial was potassium cyanide, KCN. It was known that this substance weakened or inhibited entirely a number of enzymatic processes in living material, without materially or permanently altering its structure.

It was found that normally the unfertilized egg of the sea-urchin would live in sea-water at room temperature, and maintain itself in condition for successful fertilization and development, up to a period of about twenty-three hours. After that time the eggs began to weaken. Either they could not be successfully fertilized, or, if they were fertilized, development only went on for a short time. After 32 hours the eggs could not as a rule be fertilized at all. The experiment was then tried of adding to the sea-water, in which the unfertilized eggs were kept, small amounts of KCN in a graded series, and then examining the results of fertilizations undertaken after a stay of the unfertilized eggs of 75 hours in the solution. It will be noted that this period of 75 hours is more than three times the normal duration of life of the cell in normal sea-water. The results of this experiment are shown in summary form in Table 1.

TABLE I

Experiments of Loeb and Lewis on the prolongation of life of the sea-urchin egg by KCN

Concentration of KCN	Result of fertilization after a 75 hours' stay in the solution
Pure sea-water	No egg segments
n/64000 KCN	No egg segments
n/16000 KCN	No egg segments
n/8000 KCN	Very few eggs show a beginning of segmentation
n/4000 KCN	Very few eggs show a beginning of segmentation
n/2000 KCN	Few eggs go through the early stages of segmentation
n/1000 KCN	Many eggs segment and develop into swimming larvae
n/750 KCN	Many eggs segment and develop into swimming larvae
n/400 KCN	A few eggs develop into swimming larvae
n/300 KCN	No egg segments
n/250 KCN	No egg segments
n/200 KCN	No egg segments
n/100 KCN	No egg segments

From this table it is seen that in concentrations of KCN from n/750 to n/1000 the eggs developed perfectly into swimming larvae. In other words, by the addition of this very small amount of KCN the life period has been prolonged to three times what it would normally be under the same environmental conditions. Concentrations of KCN weaker than n/1000 were incapable of producing this result, or at best if development started the process came very quickly to an end. In stronger concentrations than n/400 the eggs were evidently poisoned, and no development occurred.

Other experiments of Loeb's show that the lethal effects of various toxic agents upon the egg cell may be inhibited, or postponed for a relatively long time, by suitable chemical treatment, such as lack of oxygen, KCN, or chloral hydrate. A typical experiment of this kind made upon the sea-urchin, *Strongylocentrotus purpuratus*, may be quoted:

> Eggs were fertilized with sperm and put eleven minutes later into three flasks, each of which contained 100 c. c. of sea-water + 16 c. c. 2-1/2 m $CaCl_2$. One flask was in contact with air, while the other two flasks were connected with a hydrogen generator. The air was driven out from these two flasks before the beginning of the experiment. The eggs were transferred from one of these flasks after four hours and fourteen minutes, from the second flask after five hours and twenty-nine minutes, into normal (aerated) sea-water. The eggs that had been in the hypertonic sea-water exposed to air were transferred simultaneously with the others into separate dishes with aerated normal sea-water. The result was most striking. Those eggs that had been in the hypertonic sea-water with air were all completely disintegrated by "black cytolysis." Ten per cent. of the eggs had been transformed into "shadows" (white cytolysis). It goes without saying that all the eggs that had been in the aerated hypertonic sea-water five and a half hours were also dead. The eggs that had been in the same solution in the absence of oxygen appeared all normal when they were taken out of the solution, and three hours later—the temperature was only 15°C—they were all, without exception in a perfectly normal two- or four-cell stage. The further development was also in most cases normal. They swam as larvae

at the surface of the vessel and went on the third day (at the right time) into a perfectly normal pluteus stage, after which their observation was discontinued. Of the eggs that had been five and a half hours in the hypertonic sea-water deprived of oxygen, about 90 per cent. segmented.

Let us consider one more illustration from Loeb's work in this field. Normally, in the forms with which he chiefly worked, sea-urchin, starfish, and certain molluscs, an absolutely essential condition for the continuation of life of the germ-cells after they are discharged from the body is that two cells, the ovum and the spermatozoon, shall unite in normal fertilization. Put in another way, parthenogenesis does not normally occur in these forms. Fertilization is an essential condition for the continuation of life and development. But Loeb's painstaking and brilliant researches extending over a number of years show that when we say that fertilization is an essential condition for the continued life of the germ-cells outside the body our language tends to obscure the most important fact, which is simply that for the continuation of life in these cells only certain internal physico-chemical conditions and adjustments must be realized. It makes no essential difference to the result whether these conditions are realized through the intervention of the sperm, as in normal fertilization, or by purely artificial chemical methods initiated, controlled and directed at every step by human agency. We can, in other words, regard all cases of successful artificial parthenogenesis as fundamentally a contribution to the physiology of natural death, and a demonstration of its essentially mechanistic basis. The conditions of continued existence are physical and chemical and controllable as such. The methods finally worked out as optimum are very neat, and afford a complete demonstration of the thesis we have just stated. Thus, for example, the unfertilized egg of the sea-urchin, *Strongylocentrotus purpuratus*, will continue in life and develop perfectly normally if it is subjected to the following treatment: The eggs are first placed in sea-water to which a definite amount of weak solution of butyric acid has been added (50 c. c. of sea-water + 2.8 c. c. n/10 butyric acid). In this solution at 15° C. the eggs are allowed to remain from 1½ to 3 or 4 minutes. They are then transferred to normal sea-water, in which they remain from 15 to 20 minutes. They are then transferred for 30 to 60 minutes at 15° C. to sea-water which has had its osmotic pressure raised by the addition of some salts (50 c. c. of sea-water + 8 c. c. of 2½ m NaCl, or 2½ m NaCl + KCl + $CaCl_2$ in the proportion in which these salts exist in sea-water). After the stay of from 30 to 60 minutes in this solution the eggs are transferred back to normal sea-water, the transfer being in batches at intervals of 3 to 5 minutes between each batch transferred. It is then found that those eggs which have been just the right length of time in the hypertonic sea-water develop into perfectly normal sea-urchin larvae. In other words, we have here a definite and know physico-chemical process com-

pletely replacing what was before this work universally regarded as a peculiarly vital process of extraordinary complexity, probably beyond powers of human control.

These three examples from Loeb's work on the subject of prolongation of life in the egg cell will suffice for our present purposes. The lesson which they teach is plain, and is one which has, as will be readily perceived, a most important bearing upon the general concept of life and death outlined in the preceding paper in this series. The experiments demonstrate that the conditions essential to continued life of the germ-cells outside the body are physico-chemical conditions, and that when these cells die it is because the normal physico-chemical machinery for the continuation of life has either broken down, or has not been given the proper activating chemical conditions.

Lack of space alone prevents going in detail into another extremely interesting and important development of this subject due to Dr. Frank R. Lillie of the University of Chicago. He has in recent years made a thorough analysis of the biological factors operating when the egg of the sea-urchin is normally fertilized by a spermatozoon. The conception of the process of fertilization to which Lillie comes is "that a substance borne by the egg (fertilizin) exerts two kinds of actions, (1) an agglutinating action on the spermatozoon and (2) an activating action on the egg. In other words, the spermatozoon is conceived, by means of a substance which it bears and which enters into union with the fertilizin of the egg, to release the activity of this substance within the egg." From the standpoint of the present discussion it is obvious that Lillie's results present nothing which in any way disturbs the conclusion we have reached as to the essentially physico-chemical nature of the processes which condition the continuation of life and development of the egg.

2. Tissue Culture in Vitro

Let us turn now to another question. Are the germ-cells the only cells of the metazoan body which possess the characteristic of potential immortality? There is now an abundance of evidence that such is not the case, but that on the contrary there are a number of cells and tissues of the body, which under appropriate conditions may continue living indefinitely, except for the purely accidental intervention of lethal circumstances. Every childs knows that all the tissues do not die at the same time. It is proverbial that the tail of the snake, whose head and body have been battered and crushed until even the small boy is willing to admit that the job of killing is complete, will not die till the sun goes down. Galvani's famous experiment with the frog's legs only succeeded because some parts survive after the death of the organism as a whole. As Harrison points out "Almost the whole of our knowledge of muscle-nerve physiology, and much of that of the action of the heart, is based

upon experiments with surviving organs, and in surgery, where we have to do with changes involved in the repair of injured parts, including processes of growth and differentiation, the power of survival of tissues and organs and their transplantability to strange regions, even to other individuals, has long formed the basis of practical procedures."

The first successful cultures of somatic cells and tissues outside the body were those of Leo Loeb, described in 1897. His first method consisted in cultivating the tissues in appropriate media in test tubes. Later he used also another method which involved the transplantation of the solid medium and the tissue into the body of another animal. What has been regarded as a defect of both these methods is that they do not permit the continued observation of the cells of the growing cultured tissue. To Harrison is due the development of a method which does permit such study. In 1907 he announced the discovery that if pieces of the developing nervous system of a frog embryo were removed from the body with fine needles, under strictly aseptic precautions, and placed on a sterile cover slip in a drop of frog lymph, and the cover slip then inverted over a hollow glass slide, that the tissues would remain alive for many days, grow and exhibit remarkable transformations. By this technique it was possible to study the changes with a high power of the microscope and photograph them.

FIG. 2. PIECE OF TISSUE FROM FROG EMBRYO CULTIVATED IN LYMPH, 2 days old. The dark portion shows original bit of tissue. Lighter portions are new growth. (From Harrison.)

Figure 2 is a general view of one of these tissue cultures two days old. It shows a piece of nervous tissue from the frog embryo with cells growing out from it into the lymph. The lighter portions are the new cells. In his remarkable monograph Harrison shows nerve cells developing fibers at first thickened, but presently becoming of normal character and size. At the ends are pseudopodial processes, by which the growing fiber attaches itself to the cover slip or other solid bodies and pulls itself out, as it were. Figure 3 shows a particularly beautiful nerve fiber preparation made by Burrows.

The fibers grew from a preparation of the embryonic nervous system of the chick. There can be no doubt, as these figures so clearly show, of the life of these cells outside the body, or of the normality of their developmental and growth processes.

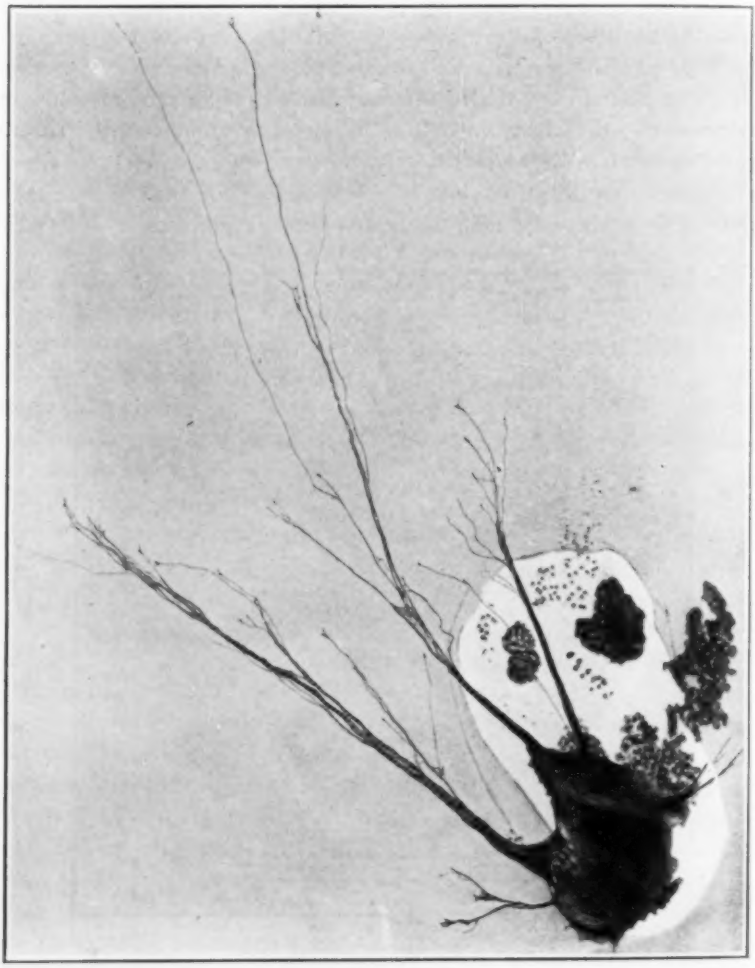

FIG. 3. GROUP OF NERVE FIBERS WHICH HAVE GROWN FROM AN ISOLATED PIECE OF NEURAL TUBE OF A CHICK EMBRYO. (From Harrison after Burrows.)

Under the guidance of Harrison, one of his students, Burrows, improved the technique of the cultivation of tissues outside the body, first by using plasma from the blood instead of lymph and later in various other ways. He devised an apparatus for affording the tissue culture a continuous supply of fresh nutrient medium. There is in this apparatus a large culture chamber which takes the place of the plain hanging drop in a hermetically sealed cell. On the top of this culture chamber there is a wick which carries the culture fluid from a supplying chamber and discharges it into a receiving chamber. The tissue is planted among the fibers of the wick, which are pulled apart where it crosses the top of the chamber. The whole system is kept sterile and so arranged that the growing tissue can be kept under observation with high powers of the microscope. The nutrient medium may be modified at will, and the effects of known substances upon the cellular activities of every sort may be studied.

Burrows began his investigations in this field on the tissues of the embryo chick. With the success of these cultures was established the fact that the tissues of a warm blooded animal were as capable of life, development, and growth outside the body as were those of cold-blooded animals, such as the frog. Burrows succeeded in cultivating outside the body cells of the central nervous system, the heart, and mesenchymatous tissue of the chick embryo. At the same time Carrel was carrying on studies in this same direction at the Rockefeller Institute. In his laboratory were made the first successful cultures in vitro of the adult tissue of mammals. He developed a method of culture on a plate which permitted the growing of large quantities of material. He found that almost all the adult and embryonic tissues of dog, cat, chicken, rat, guinea pig, and man could be cultivated *in vitro*. Figure 4 shows a culture of human tissue, made at the Rockefeller Institute. I am indebted to Doctor Carrel and Doctor Ebeling for permission to present this photograph here.

According to the nature of the tissues cultivated, connective or epithelial cells were generated, which grew out into the plasma medium in continuous layers or radiating chains. Not only could normal tissues be cultivated but also the cells of pathological growths (cancer cells). It has been repeatedly demonstrated that normal cell division takes place in these tissues cultivated outside the body. The complex process of cell division which is technically called mitosis, has been rightly regarded as one of the most characteristic, because complicated and unique, phenomena of normal life processes. Yet this process occurs with perfect normality in cells cultivated outside the body. Tissues from various organs of the body have been successfully cultivated, including the kidney, the spleen, the thyroid gland, etc. Burrows was even able to demonstrate that the isolated heart muscle cells

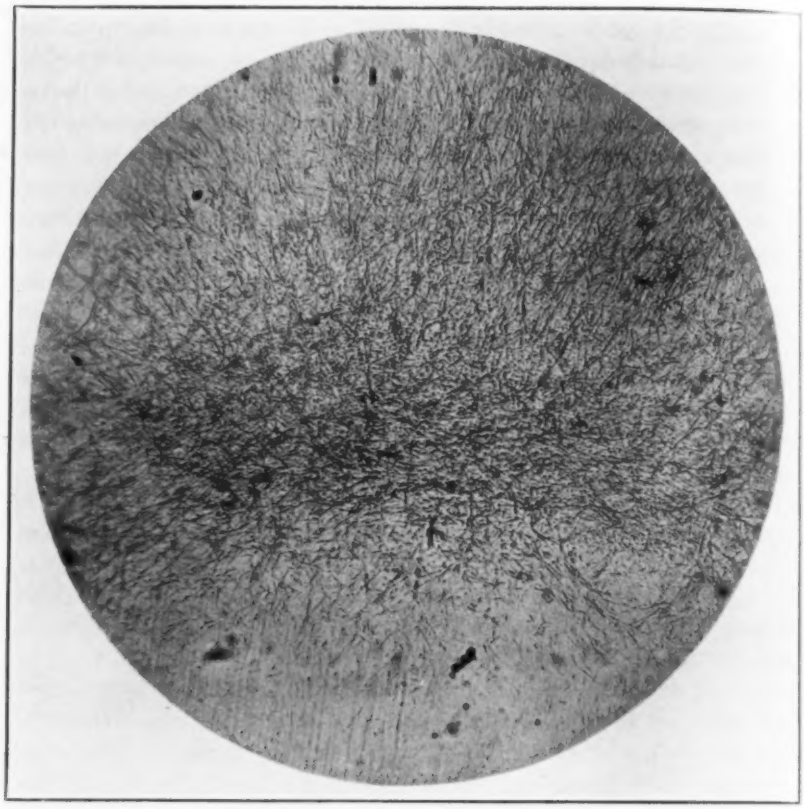

FIG. 4. HUMAN CONNECTIVE TISSUE CELLS FIXED AND STAINED WITH GIEMSA STAIN. The culture was made by extirpating the central portion of culture 285 in its 16th passage, washing the remaining portion of the culture with Ringer solution without removing it from the cover-glass, and dropping on fresh plasma and extract. The preparation shows the extent of growth obtained in 48 hours from peripheral cells remaining after extirpation of the fragment. (After Losee and Ebeling.)

of the chick embryo can divide as well as differentiate and beat *rhythmically* in the culture medium.

Perhaps even more remarkable than the occurrence of such physiological activity as that of the heart muscle cells *in vitro* is the fact that in certain lower forms of life a small bit of tissue or even a single cell, may develop in culture into a whole organism, demonstrating that the capacity of morphogenesis is retained in these isolated somatic cells. H. V. Wilson has shown that in coelenterates and sponges complete new individuals may develop *in vitro* from isolated cells taken from adult animals. By squeezing small bits of these animals through bolting cloth he was able to separate small groups of cells or even single cells. In culture these would grow into small masses of cells which would then differentiate slowly into the normal form of the complete organism. Figure 5 shows an example of this taken from Wilson's work.

It was early demonstrated by Carrel and Burrows that the life of the tissues *in vitro* which varied in different experiments from 5 to 20 days could be prolonged by a process of successive transfers of the culture to an indefinite period. Cells which were nearing the end of their life and growth in one culture need only be transferred to a new culture medium to keep on growing and multiplying. Dr. and Mrs. Warren H. Lewis made the important discovery that tissues of the chick embryo could be cultivated outside the body in purely inorganic solutions, such as sodium chloride, Ringer's solution, Locke's solution, etc. No growth in these inorganic cultures took place without sodium chloride. Growth was prolonged and increased by adding calcium and potassium. If maltose or dextrose, or protein decomposition products were added proliferation of the cells increased.

By the method of transfer to fresh nutrient media Carrel has been able to keep cultures of tissue from the heart of the chick embryo alive for a long period of years. In a letter recently received he says: "The strain of connective tissue obtained from a piece of chick heart

FIG. 5. PENNARIA. Restitution mass six days old, completely metamorphosed, with developed hydranths. Op. perisarc of original mass; x, perisarc of outgrowth adherent to glass. (From Wilson.)

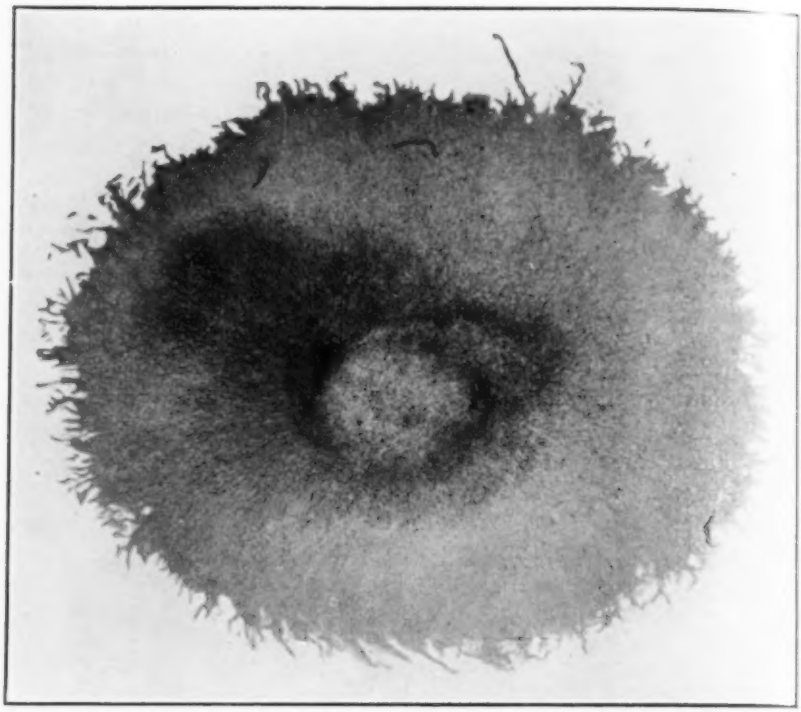

FIG. 6. CULTURE OF OLD STRAIN OF CONNECTIVE TISSUE. 1614 passage. 8 years and 8 months old, lacking 2 days. 48 hours' growth. x20. (Ebeling.)

is still alive and will be *nine years old* the seventeenth of January, 1921." Figure 6 is a photograph showing the present condition of this culture.

This is indeed a remarkable result. It completes the demonstration of the potential immortality of somatic cells, when removed from the body to conditions which permit of their continued existence. Somatic cells have lived and are still living outside the body for a far longer time than the normal duration of life of the species from which they came. I think the present extent of Carrel's cultures in time fully disposes of Harrison's criticism to the effect that we are "not justified in referring to the cells as potentially immortal or even in speaking of the prolongation of life by artificial means, at least not until we are able to keep the cellular elements alive in cultures for a period exceeding the duration of life of the organism from which they are taken. There is at present no reason to suppose this cannot be done, but it simply has not been done as yet." I have had many years' experience with the domestic fowl, and have particularly studied its normal duration of life, and discussed the matter with competent observers of poultry. I am quite sure that for most breeds of domestic poultry

the normal average expectation of life *at birth* is not substantially more than two years. For the longest lived races we know this normal average expectation of life cannot be over four years. I have never been able to keep a Barred Plymouth Rock alive more than seven years. There are on record instances of fowls living to as many as 20 years of age. But these are wholly exceptional instances, unquestionably far rarer than the occurrence of centenarians among human beings. There can be no question that the nine years of life of Carrel's culture has removed whatever validity may have originally inhered in Harrison's point. And further the culture is just as vigorous in its growth today as it ever was, and gives every indication of being able to go on indefinitely, for 20 or 40, or any desired number of years.

The potential immortality of somatic cells has been logically just as fully demonstrated in another way as it has by these tissue cultures. I fully agree with Leo Loeb when he says that the proof of potential immortality "can just as well be supplied by serial transplantation of tissues in the living body; but we can, I believe, go further, and state that as far as such potential immortality of tissues can be proved, the proof has already been given through the long-continued, apparently endless serial transplantation of tumors. Now tumor cells are merely ordinary somatic cells living under special conditions; and we may, therefore, conclude that, in the same sense as protozoa and germ cells, also, certain ordinary mammalian somatic cells possess a potential immortality." Loeb first announced this important conclusion nineteen years ago. To him unquestionably belongs the credit for first perceiving that death was not a necessary inherent consequence of life in the somatic cell, and demonstrating by actual experiments that somatic cells could, under certain conditions, go on living indefinitely.

Before turning to the next phase of our discussion let us summarize the ground we have covered up to this point. We have seen that by appropriate control of conditions it is possible to prolong the life of cells and tissues far beyond the limits of longevity to which they would attain if they remained in the multicellular body from which they came. This is true of a wide variety of cells and tissues differentiated in various ways. Indeed, the range of facts which have been ascertained by experimental work in this field probably warrants the conclusion that this potential longevity inheres in most of the different kinds of cells of the metazoan body, except those which are extremely differentiated for particular functions. To bring this potential immortality to actuality requires, of course, special conditions in each particular case. Many of these special conditions have already been discovered for particular tissues and particular animals. Doubtless, in the future many more will be worked out. We have furthermore seen that in certain cases the physico-chemical nature of the conditions necessary to insure the continuance of life has been definitely worked

out and is well understood. Again this warrants the expectation that, with more extended and penetrating investigations in a field of research which is really just at its beginning, we shall understand the physics and chemistry of prolongation of life of cells and tissues in a great many cases where now we know nothing about it.

One further point and we shall have done with this phase of our discussion. The experimental culture of cells and tissues *in vitro* has now covered practically all the *essential* tissue elements of the metazoan body, even including the most highly differentiated of those tissues. Nerve cells, muscle cells, heart muscle cells, spleen cells, connective tissue cells, epithelial cells from various locations in the body, kidney cells, and others have all been successfully cultivated *in vitro*. We may fairly say, I believe, that the potential immortality of all the essential cellular elements of the body either has been fully demonstrated, or else has been carried far enough to make the probability very great that properly conducted experiments would demonstrate the continuance of the life of these cells in culture to any definite extent. It is not to be expected, of course, that such tissues as hair, or nails, would be capable of independent life, but these are essentially unimportant tissues in the animal economy as compared with those of the heart, the nervous system, the kidneys, etc. What I am leading to is the broad generalization, perhaps not completely demonstrated yet, but having regard to Leo Loeb's work, so near it as to make little risk inhere in predicting the final outcome, *that all the essential tissues of the metazoan body are potentially immortal*. The reason that they are not actually immortal, and that multicellular animals do not live forever, is that in the differentiation and specialization of function of cells and tissues in the body as a whole, any individual part does not find the conditions necessary for its continued existence. In the body any part is dependent for the necessities of its existence, as for example nutritive material, upon other parts, or put in another way, upon the organization of the body *as a whole. It is the differentiation and specialization of function of the mutually dependent aggregate of cells and tissues which constitutes the metazoan body which brings about death, and not any inherent or inevitable mortal process in the individual cells themselves.*

3. Senescence

A careful and unprejudiced examination will suffice to convince anyone of open mind, I think, that much of the literature on senescence is really of no fundamental importance, because it has unwittingly reversed the true sequential order of the causal nexus. If cells of nearly every sort are capable, under appropriate conditions of living indefinitely in undiminished vigor, and cytological normality, there is little

ground for postulating that the observed senescent changes in these cells while in the body, such as those described by Minot and others, are expressive of specific and inherent mortal processes going on in the cells, or that these cellular processes are the *cause* of senescence, as Minot has concluded. It would rather appear that these visible cytological changes are expressive of effects not causes, and that they are the effects of the organization of the body as a whole as a system of mutually dependent parts, and not of specific, inherent and inevitable cellular processes.

Cells in culture *in vitro*, as we have seen, do not grow old. We see none of the characteristic senescent changes in them. From these facts it is a logically cogent induction to infer that when cells show the characteristic senescent changes, which were discussed in the preceding paper, it is because they are reflecting in their morphology and physiology a consequence of their mutually dependent association in the body as a whole, and not any necessary progressive process inherent in themselves. In other words we may justifiably, in the light of our present knowledge as I believe, regard *senescence as an attribute of the multicellular body as a whole*, consequent upon its scheme of morphologic and dynamic organization. This attribute is reflected morphologically in the component cells. But it does not originate in the cells, nor does it ever occur in the cells when they are removed from the mutually dependent relationship of the organized body as a whole. In short senescence is not a primary attribute of the physiological economy of cells as such.

If this conception of the phenomenon of senescence is correct in its main features, as I believe it is, it shows the essential futility of attempting to investigate its causes by purely cytological methods. On the other hand, by clearing away the unessential elements, it indicates where research into the problem of causation of senescence may be profitable.

MOTION PICTURES AND CRIME

By Dr. A. T. POFFENBERGER
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ONE of the surprising things about the wave of crime which is reported to be raging throughout the country is the large number of very young persons found implicated in crimes of all sorts. Much attention has recently been given to the matter in newspaper articles and editorials, and blame is placed rather frequently upon the motion picture. Various sorts of censorship have been proposed, most of them drastic in form. The following article taken from a recent issue of the New York *Times* will serve as an illustration:

> Motion pictures portraying criminals at work have been barred in————. Chief of Police ———— announced today that three weeks ago he had given orders to movie censors not to issue permits for any screen drama that showed a crime committed, even though the end of the picture might show the criminal in a prison cell.
>
> "It will make no difference whether the criminal shown is a hero or a villain," said the chief. "Even the showing of a policeman disguised as a burglar is taboo."
>
> The order became public when three youthful robbers, who were sentenced to the State Reformatory, said their crimes had been inspired by a "crook" moving picture.

Prohibitions and censorships of any sort are distasteful to the American people, except in cases where the general welfare can be proved to be at stake. Therefore an inquiry into the accusations that have been made against the motion picture seems justified at this time when attention is being centered upon the means of crime prevention. The question is a psychological one, and concerns the effects of motion picture experience upon the mind of the young person. The average adult can not interpret the reactions of a child in terms of his own reactions, because there are fundamental differences between the two. A knowledge of child psychology is needed to understand what the motion picture means to the child.

As an agent of publicity, with its immense daily audience of young people, it has great possibilities for creating and developing in them a spirit of true Americanism, a respect for law and social order which are recognized as essentials for a democracy. Rightly used, the motion picture is indeed one of the most powerful educational forces of the twentieth century. Its possible influence in the Americanization of our foreign population, through a medium which shall be intelligible to all, regardless of race, is scarcely yet realized. But wrongly used and not carefully guarded, it might easily become a training school for

anti-Americanism, immorality and disregard for law—a condition in which each individual is a law unto himself. We have therefore, in a sense, to meet an emergency, to begin in time to make of this truly public school the kind of educational force that it should be—to prevent rather than to prohibit.

In a consideration of the young, we must not fail to include that great class of unfortunates designated as the mentally deficient. They are individuals, who, though physically and chronologically adults, are still children mentally. The problem of the mentally retarded individual is essentially the same as that of the normal person of younger years. The moron, the highest type of the feeble-minded, usually defined as an individual whose mental development has ceased at about the age of eleven years, has most of the mental traits of the child of eleven years. He has, however, the physical strength, instincts and desires of the adult. The moron is seldom confined in an institution, because his defects are not considered by family and friends as great enough for that. As a result, this type of individual is at large, and must be protected from evil suggestions and from too complex an environment. Such persons, when the higher forms of control which they lack are supplied by guardians or are made unnecessary by simplified living conditions, may well become useful and self-supporting members of society. Without this control, they constitute a real danger, since their physical age, which may be from fifteen years up, places them in a position to act upon evil suggestions more readily than the child.

What, then, are the mental characteristics of these two groups, children and mentally deficient adults, which mark them off from normal adults?

One respect in which they differ from the adult is in suggestibility; another is the lack of ability to foresee and to weigh the consequences for self and others of different kinds of behavior; another is the lack of capacity and willingness to exercise self-restraint; and still another is an imagination less controlled and checked by reference to the realities. All these traits taken together make the child and the mentally deficient person especially susceptible to evil influences. That is why one expects the majority of certain kinds of crimes to be committed by persons of retarded mental development. And recent statistical studies of the relation between crime and mental defect confirm the expectation. One needs only to recall the epidemics of suicide and murder by such means as cyanide of potasium, chloride of mercury, carbolic acid and the like; to notice the likenesses in the technique of burglars at different periods of time; to note the cases of false testimony in court and false confessions of crime to realize the great suggestibility of such persons and their lack of foresight. Unlike the

normal adult, they are unable to resist the suggestions of advertisements, posters, newspapers and magazines, and of their associates. Naturally, these traits may be played upon either for good or evil. One who knows the mechanism of suggestion would expect the prevalence of crime, especially when it is advertised by these agencies of publicity, to breed more crime.

Motion pictures, containing scenes vividly portraying defiance of law and crimes of all degrees, may by an ending which shows the criminal brought to justice and the victory of the right, carry a moral to the intelligent adult; but that which impresses the mind of the mentally young and colors their imagination is the excitement and bravado accompanying the criminal act, while the moral goes unheeded. Their minds can not logically reach the conclusion to which the chain of circumstances will drive the normal adult. A little questioning of such persons who attend moving pictures and read stories will indicate how different are the factors which impress their minds, from those which impress the intelligent adult. This failure to grasp the significance of the story is even more pronounced when it is conveyed only by the posters advertising it. Here it seems to be the rule to portray only the most glaring and exciting portion of the plot with no possibility of right interpretation. A survey of any group of posters advertising motion pictures, with only their direct appeal in mind, will show a surprisingly large portion of them suggesting murder, burglary, violence or crime of some sort. The pistol seems to be one of the commonest of the stage properties of the motion picture advertisement. And a very frequent pose is that of the frenzy of rage and the clenched fist ready to strike a blow. Those young people and even adults who are limited to the advertising posters for their entertainment may get evil and anti-social suggestions from them. Considering the almost unlimited audiences which the advertising posters command, their careful control would seem a greater necessity even than that of the play itself.

It is just on account of this susceptibility to suggestion that the mentally retarded criminal and the child criminal need a special kind of treatment and special courts to handle their cases. Indeed, much has been done in recent years toward the proper treatment of these two classes of criminals. What needs most emphasis now, however, is prevention, not cure. Proper control of their environment is the one factor which will do much to make of these two classes respectable members of society instead of criminals.

There are many sources of evil suggestions which can not be eliminated, so long as there are immoral and anti-social persons, and to that extent the atmosphere in which children develop and the feeble-minded live, must remain far below the ideal. But that is a good rea-

son why those evils which can be eliminated should be. Such organs of publicity as moving pictures, newspapers, magazines, advertising posters and the like, should not be allowed to contribute to the necessary burden of evil suggestion by the character of their productions. The purely commercial spirit should be tempered by a spirit of social welfare and education.

The matters here discussed have not entirely escaped attention hitherto. For instance, there was introduced, some time ago, into the New York State legislature a bill providing for the limitation by newspapers of the publicity which may be given to reports of crime. The width and height of headlines for such material was specified. The nature of these provisions does not especially concern us here, but the fact that the matter is receiving attention is interesting.

These are preventive measures applied from the outside. The remedy should come from within. It can be done, and in fact has been done by newspapers. A survey, recently made of a large number of metropolitan newspapers, shows that they differ strikingly in the way they handle reports of crime. In some cases crimes are not featured in big headlines and favored positions, and only facts that the reading public can profit by knowing are printed. If the motion picture is to become the educational force that it is capable of becoming, the censorship must be an internal one. The old notion is outworn that it is necessary "to give the people what they want." It is the function of an educational medium and an entertaining medium also, to give the public what they should have, in order that they may learn to want it. The function of education is to create as well as to satisfy wants. The future of the motion picture is limited only by the foresight of its leaders.

AN ITALIAN BOOK ON EMPEDOCLES

By JONATHAN WRIGHT, M. D.
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THE recent appearance of an Italian book* on Empedocles emphasizes the growing conviction among historians of science that this almost mythical figure not alone furnishes us with a tie that binds the birth of science with magic, but that the fragments of his verse contain the germs from which sprang much of the subsequent medicine and not a little of the physics of the later Greeks. It also illustrates how impossible it is, even in a treatise of some six or seven hundred pages, to give any coherent account of him. Almost every line of the one hundred and fifty odd fragments lends itself to comment, but the comments of modern critics diverge into paths leading into fields of science, religion, medicine, poetry—all now quite remote from one another, but very much less so when the ancient commentators recorded his sayings and their criticisms on them in the "testimonials," Bignone calls them, ninety-eight in number, which the industry of German and Italian authors have assembled for us. To one interested as I have been in this ancient Sicilian of the old Magna Graecia the book, which I suppose from the mischance of war has been long in falling into my hands, is a veritable mine. Several of my essays on Empedocles have found their way into various journals of more recent issue. Nevertheless this book of the modern Italian cult of the history of science tempts me again to venture, under the veil of reviewing it, to say something of its subject, despite the impossibility of avoiding some repetition even of matter published in this journal.

In the review of a book the lack of coherency can be more readily pardoned than in an essay even on Empedocles, since in one there must be at least a leading thread of interest that binds disparate parts together, while in the other the writer is licensed to pick here and there subjects for his desultory converse with his readers. This is a privilege to be cherished when one has to deal with a personality of striking interest and at the same time with trends of thought which diverge so widely in modern time as does that of this citizen of Agrigentum, whose mouldering walls have been levelled in the dust of twenty-four centuries. Incoherence in the review of a necessarily incoherent book on the fragments of two poems as old as the Carthaginian invasion which levelled them can hardly be unexpected, but it can be avoided somewhat by omissions supplied to some extent

*Bignone, Ettoré: I Poeti Filosophi della Grecia Vol. II. Empedocle Torino 1916.

in what I have previously written. When the reader comes to realize how the phrases preserved to us lead us off into the most distant, the deepest and the most exalted, realms of thought and yet often perceives that much which floats on the surface is really the froth of the human intellect, blind alleys of the mind and not a film on the surface which hides sunken treasures below, he must thereby be aware that we are in the infancy of intellectual development. Germs of mighty things, too, lie hidden in a chaos of confused activities of the mind, in a welter of striving after the truth which are scarcely more than instincts and impulses, but which have after all led nascent civilizations to their destiny.

I give the plural form to civilization, because the Greek civilization, which sprang up like a mushroom during the next generation, in the foot tracks of Empedocles, and his fellows, was not the only sprout from the germs that lay hidden in their thoughts. His genius was not altogether Greek, perhaps not essentially Greek at all, it is pointed out. The youth of the modern world was his epoch. He initiated tendencies, subsequently renewed by others, it is true, but his own cultural ancestry was Greek and Hindu fused into one. He animated not only the medicine of Hippocrates, but the sublime imaginings of the Neo-Platonists[1] and the industry of the Arabian successors of Alexandrian science, though on reference to Clement of Alexandria[2] I see no reason why Bignone should think from the text he looked on him with a benignity he was unaccustomed to accord to science, due to the declaration of Empedocles that he distrusted the evidences of sense. He was an orientalist and a westerner, a mystic and a man of science. In a world of autocracy he belonged to democracy. His thaumaturgy and his grovelling before a crowd were a part of it. Much of the philosophy of the Greeks after Aristotle came from the all but forgotten subterranean springs of Alcmaeon and Empedocles. His inspiration, for the most part unrecognized, of Alexandrian mysticism, flowing through Plato, found and made fertile the arid sands of Africa in which his own intellectuality had its origin. His affiliation, as I have pointed out before this Italian book came under my observation, was Egyptian. Sicily was the stepping stone from Carthage across the Mediterranean to the European continent. We see the stamp of the African on the face of immigrants from Sicily and lower Italy today, as they step on the wharves of Ellis Island.

We dimly see in the records, perhaps, his leanings to democracy but we observe the whisperings of oriental plotting, the silence of fear in the face of oriental despotism. His revolt, if such it was, in the interests of the people, was an oriental revolt. It was African. It is

[1]Whittaker, Thomas: The Neo-Platonists, 2nd ed. 1918. Cambridge University Press.

[2]Clement of Alexandria, transl. by G. W. Butterworth, Loeb Classics. Putnams 1919, pp. 55 and 145.

told that at a banquet given by the new democratic reform government of Agrigentum, already suspected of reactionary tendencies, Empedocles took note the people were not served with drink. Angered he told the waiters to pour wine for the common people, but they said they must wait for the magistrate of the council. When the latter arrived he was made king of the feast and set up a tyrannical rule saying they *must* drink and if any disobeyed wine should be poured on their heads. Empedocles did not breathe a word, but the next day, in his capacity of judge in the courts, he condemned to death both the arrogant bureaucrat and the chief under whom he served. The incident is rather mutilated in the telling, but it seems to bear the marks not only of a drunken brawl but of an oriental conspiracy. In some such way as this, quoted in the laconic language of Diogenes Laertius from the Sicilian historian, Timaeus, he began his revolt. He may have been the "champion of civil liberty," in the phrase of a modern Italian patriot, but some of us westerners wonder a little how a trivial affront could be magnified into a revolution which overthrew the government of a city of eighty thousand souls. We have to imagine the hidden undercurrents of discontent and suspicion and of fear that the Carthaginians were soon to come again as invaders, as indeed they did. For Agrigentum arose and flourished between one African invasion and another a century or two later. Quickly after the repulse of the first one, the fertile hinterland of Sicily poured its riches into the seaport and the commerce which enriched Agrigentum made her luxury and prodigality a byword of the Sicilian coast and the neighboring shores of Italy and reached the ears of the poverty stricken peasants of Greece itself. Sicily was the Eldorado, the California of the nascent civilization of Greece—and its grave, we may say, after reading the thrilling pages of Thucydides' account of the Sicilian expedition in which perished the flower of Athenian youth and her power, but we are still nearly a hundred years before that tragic event. Agrigentum survived it for a few years and was then overwhelmed herself by the Carthaginians, but the motive at the bottom of the Athenian venture—and probably of the Carthaginian also—was plunder. It had been told Agrigentum plutocrats were accustomed at festivals to stand in the highways and invite pleasing travelers to their hospitality. The foreigners had heard doubtless the funny story of the drunken revel when the banquet room reeled so in the sight of the feasters they thought they were in a bark tossed by stormy waves. To lighten ship the wine sick crew threw the goblets and platters and cushions out of the window. It is said of Plato, but it probably was some one else, when he came to visit Agrigentum, that he remarked: "They glut themselves with sensual pleasures as though they expect to die tomorrow and build their palaces as though they expect to live forever."

This was the environment of Empedocles. He was the product of ancient riches and had the time for culture which an opulent, even a sordid, environment gives to its fortunate ones, and we find it quite natural that he should be bitten by "parlor socialism." We indulge in a little doubt if he took the long chance in carrying out such ideas, but that is modern cynicism. It may have been different then. Very likely the paths of commerce over which had flowed the wealth of his family also brought to him as to the modern man of leisure the culture of the East. Doubtless it was thus the influences of the ancient civilizations, more than his own possibly extended travels, were exerted upon him, but there was an indigenous source of his mysticism, at least, which was less directly derived from the other continents that border the middle sea. Orpheus is but a name, scarcely more than legend, but he stands as a symbol in the history of Ancient Greece representing a psychological fragment of the life of a people, yet having a profound influence upon the mysticism and the philosophy which marked them and gave them a hue only occasionally visible at the period of their greatest glory. Later it sprang into prominence in the neo-Platonic philosophy and became assimilated to the religion of Christ. Just as we are able to perceive that the mysticism of the East always remained, at least in its essence, a heterogeneous element in the philosophy of the Periclean Greeks, so we perceive that the Orphic spirit, the yearning after immortality, the clinging to the supernatural is submitted in the dialogues of Plato to a searching analysis by Socrates which it has never received at the hands of Christian exegetists. Before them there had been no discussion of the immortality of the soul. Unquestioning faith in matters devoid of rational support was unknown to the intellectual processes of the Greeks of the golden age. The defiance of the Christian mysticism which declared belief in the miracle because it was impossible, would be incomprehensible in the personages of the Platonic dialogues. It is unknown to Plato no less than to Hippocrates and Aristotle, but Empedocles imagined a time when the universe was governed by physical laws unknown to our cosmology and Huxley, the modern rationalist and archmaterialist, declined to assert that our present knowledge is sufficient to lend any force to the assertion that nothing has ever happened outside the domain of natural law. We get traces of Orphic mysticism in Pindar and in Hesiod. In the theogony of the latter we can perceive the marks of Egyptian and Mesopotamian influence or that of the brown people who once filled the basin of the Mediterranean. How far either of these currents made up the stream of Orphism is not very clear. We can not help suspecting that Orpheus and the Thracian poets or rhapsodes are figures we see in a blurred way through the veil which hides the ancient Mycenian culture of letters, if there was one, from us. At any rate what is a mere trace in Pindar

and in the still earlier Hesiod we find more pronounced not only in the fragments of his lustral poem but in those of the verses on cosmic philosophy by Empedocles.

In both of these hints of his relationship with the Pythagoreans seem very insistent, but how much the teachings of Pythagoras owe to a chthonic Orpheus and how much they owe to the curricula of the temples of Sais and Letopolis, how much is native Greek, how much is imported Egyptian, how much is a heritage from the peoples who antedated the supposed irruption from the north is still a question for Evans and the archeologists of the Aegean civilization. It is supposed to be Pythagoras to whom Empedocles alludes as a man of superhuman wisdom, of great prophetic power and vast mortal knowledge (frag. 129). Empedocles was born (492 B. C.?) probably not long after the death of Pythagoras and Alcmaeon, from the latter of whom Empedocles is supposed to have derived much of his philosophy, especially his medicine, is thought to have been a cautious follower of Pythagoras and, perhaps in his youth, a personal one. Empedocles, Pythagoras and Democritus, according to Philolaos, belonged among the Magi. This item of information is not specifically in accord with other testimony, but we have no knowledge how far into Greece the doctrine of the Persians penetrated during the domination of their empire in the Mediterranean. The term Magi was then doubtless interchangeable with that of philospher in our sense, but Pythagoras and Empedocles are not commonly spoken of as Magi. Democritus however and his father were on good terms with Xerxes and they were intimately associated at the time of the great invasion with the Magi who followed in the wake of the Persian myriads. It is in those of Pythagoras and Empedocles rather than in the traditions of Democritus that we surmise the influences of the Zoroastrians.

I should like to dwell on the excellence of the versification of Empedocles, to which Symonds[3] has paid tribute. Bignone hardly alludes to it and I am too lame in my Greek leg, at best, and all but helpless in the archaic and mutilated lines of Empedocles. Aristotle makes the rather paradoxical remark that he resembled Homer only in the metrical form of his poems, and one hardly knows whether to take that for a compliment or not.

I have emphasized the mystic side of the multiform legends of Empedocles, in spite of the fact it is not so clearly brought out as would seem helpful in the monograph I am taking for a text. Of all the activities of the mind affiliated with the earliest scientific thought, medicine can least afford to be blind to that side of it in the history of science. That is par excellence the *fons et origo* of its being. Modern commentators frequently refuse the name of science to medicine, but as we recede into the mists that hide its source, the one thing

[3]Symonds, John. Addington; Studies of the Greek poets, 2 vols. London. Block. 1902.

that looms up to us in absolute reality, though in uncertain outline, is the fact that science and medicine were indissoluble only when they were permeated with mysticism and a part of religion. Empedocles was a pupil of Parmenides at Elea and it is clear that he absorbed the ideas of the earlier Nature Philosophers, especially those of Heraclitus, but he was a poet as well as a philosopher; he was a conjuror who called the dead to life, a wizard with a tendency to pomp and parade and a flaunting of purple garments before the people, shod with brazen, some say golden, sandals. Like the Nigger Jim, when he confided to Huck that he "knowed most everything," he assured his favorite disciple, Pausanias, in solemn flowing verse that he knew about all there was to be known, about medicine especially, and was ready to impart all that mortal man could understand to any seeker of knowledge. Despite disclaimers of the more sophisticated, who know such things don't look well in cold print, one occasionally encounters such exalted and nave notions of the omniscience of modern science. One who has contributed much to it I once heard remark that the causes of about all disease are now known, so that unfortunately there was not much left for an anxious researcher to do in that direction. Alexander weeping for other worlds to conquer was also among the mourners. We see how natural it was for the pantheistic Empedocles, the thaumaturge and the mystic, to declare that in the final analysis prophets become poets and physicians.

He was by virtue of this primitive communing of man with nature, the first to question nature in all its comprehensiveness by any rational and experimental method and, as has been said, his theories, though frequently disputed and confuted, became the heritage of the ages that followed him. He was the first to introduce into Greek physics the idea of a force which operates on matter. For him it was not only the latter which occupied space, but the attributes of matter themselves, inclusive of the motive forces of attraction and repulsion, or as he symbolized them, Love and Hate. They had not only extension in space but consciousness. Indeed if God is force and not a neo-Platonic god above both force and matter, there is no denying this to modern theists. All ancient Greek philosophers confounded consciousness with knowledge. This Empedocles insisted upon. To deny it we are at once betrayed into hair-splitting verbal differentiations and we have to close the discussion by declaring that at least a discrimination is necessary in the analysis of phenomena and if the mystic says he knows a thing because of his consciousness alone he lays claim to powers we rationalists have no conception of and he also readily drifts also into the attitude of the Nigger Jim. Yet since we have to assume the existence of time and space from the same necessity, its metaphysical and irrational quality is no refutation of a consciousness which goes beyond knowledge. Modern science can no more get away from the

unknowable, if it wishes to advance, than religion can. It can no more afford to ignore it than religion can ignore knowledge. The one must wrest the knowable from the unknown and the other can not recede entirely into the unknowable without disappearing altogether. This was better understood by ancient philosophers than by modern scientists for they were in closer contact with the idea of primitive man that the soul is just like other matter. It was all soul or all matter for him. Even for Locke the soul was a substance, but Pythagoras saw souls dancing in the sunbeam. It would have been of no use for a modern physicist to tell an ancient Egyptian that they are small aggregates of molecules, corpuscles of real matter intercepting and reflecting light. The Pythagorean would have said, "Certainly, why not?" We have gone a little further and have divided and subdivided these "souls" and have found them loaded with energy, made up wholly of energy, something very much like "force" indeed. So Empedocles, in separating force from matter, yes, even in being a pluralist instead of a monist, in leaning towards a tetrad of elements, instead of frankly accepting the view of Heraclitus and Parmenides that they are but mutations of a single thing, force, energy if you will; in this attitude Empedocles lay athwart the current of ancient thought, just as there are some physicists today who refuse to accept a pure monism. We would never have been anywhere in science if this revolt had *not* stemmed the precipitation of ancient logic. It was necessary for practical reasons, for analysis, for foreshortening the field of cosmic facts, for luring the investigator on to the incidental discovery of some of them, to believe in a false theory. A multiplicity of material elements, like a multiplicity of souls, was necessary to the human mind to account for phenomena until it had behind it the heritage of ten thousand years of thought. Most knowledge was arrived at in this way, built up from scaffoldings of erroneous theory. It is only occasionally that any such structure preserves such substantial parts as the atomic theory, but the very name of it, indivisibility, we have nullified in splitting the atom. Aristotle declared Empedocles grouped together with the elements his two forces, Love and Hate, and Bignone finds authority that thus he was sometimes credited with making six elements, but Aristotle says there were thus logically but two because he placed them and the other elements in apposition to one another—force and matter. We would say this makes him a dualist and keeps him still in court in modern times.

Empedocles was no less a philosopher, but too much of a poet, when he called the oceans the sweat of the earth, yet it must have been a comfort to his disciples, still clinging to the mutational doctrines of the monists. He recognized there was sweet water in the sea and it is not at all certain that Aristotle[4] was not describing in a faulty manner an experiment of Empedocles instead of having performed it

himself when he asserted that if anyone will make a thin *waxen* flask, cork it, and sink it empty in the sea, in a night and a day it may be taken up full of water which is drinkable. He recommends the wrong (?) material for the flask, it would seem, but it is quite in line with the klepsydra experiment of Empedocles which Aristotle ascribes to him. I am avoiding further reference to Empedocles as an experimentalist, for to that I have already referred elsewhere, but he was as well an observer of facts, spread around him in the volcanic regions of the Mediterranean, for he recognized the igneous origin of some rocks and the aquaeous origin of others. If we thus get a glimpse of geology we turn to his idea of the sphere and we get one of geometry and find in it the origin perhaps of the Ptolemaic astronomy, much obscured it is true by mysticism and metaphysics, but essentially similar. The mystic part of it is said to have been Eleatic philosophy and we find that element of it again in Plato. The Pythagorean flavor of it is however apparent. Geometrically the sphere is a solid body, but mystically it is a divine, because a perfect, body inasmuch as it is of a mass the greatest, in proportion to its extent of periphery, of any possible geometric figure. Plato reasoned thus and it is probable that it was this geometric thought, "of a sphere, round, equal in everything to its own self," which led Empedocles to choose that form as the figure of God, the first gleam we get from a deist of a conception which is not anthropomorphic. Whether this identifies God with the universe itself I do not clearly understand, but it seems very probable that this was a pantheism worked out in details and carried to its logical conclusion. In a sphere turning around the earth he set the fixed stars like gems in a bracelet, but the planets were free and he looked upon the moon as torn off from the sun, which itself is the reflection of the fire of the whole universe. The testimony of doxographers as to these details of Empedocles' astronomy are confusing and contradictory, perhaps tinctured, some of them, with the later Ptolemaic formulas, and it is difficult to say how far he went in this scheme, but Aetius speaks of his view that the pole of the earth was inclined, presumably obliquely to the plane in which the sun performed its revolutions around it (?) in the revolving sphere. Like Thales he understood the nature of the lunar eclipses.

Now the space between the heavenly bodies he thought filled with demons and this belief is also ascribed to Thales by Laertius Diogenes. To my mind this is another significant hint they both had their astronomy direct from Babylon where the imaginations of the inhabitants filled the air they breathed with them, and all circumambient space. It is a heterogeneous pantheism but a logical one, the conception of spirits instead of a spirit pervading all. If a void or a vacuum or non-being, is as real a thing as being or matter, then the

[4]Aristotle: History of Animals, Lib. VIII, Cap. 3. II. Bohn, p. 198.

spirits become more mystical still for all but the Eleatics.

We see the pantheism of the atmosphere more primitive men breathed, though the experiments of Dr. Bose of late years, himself an orientalist, but confirms the assertion of Empedocles, twenty-five hundred years ago, that plants like all nature are endowed with sensibility and give responses to their environment, which are easily recognized by the comparatively modest extension technical art has given to man's senses. The physicists are now teaching us that the earth itself is constantly shifting its mass. For Empedocles like the plants and animals it breathes and sweats. It is not chiefly because Dr. Bose and Empedocles are orientalists and were penetrated deeply by ancient pantheism, though that at least gave direction to the earlier thinkers thoughts. It is because the conclusions of Empedocles, however arrived at, contain the germs of truth in rich abundance. It was not orientalism which established the reality of the "emanations" of nature, essential in the belief of primitive man and carrying Empedocles to unverifiable and absurd deductions, it was the revelations of occidental science of that very spirit, spirits if you are a pluralist, that lies at the bottom of primitive pantheism. The theory of sight which Empedocles constructed, so irreconcilable with facts both ancient and modern, rested upon corpuscles (electrons) flying from the object to the eye, though in his view those that fly from the eye to the object were quite as important and given more prominence in his fragment on vision and the anatomy of the eye as recorded by Aristotle. Gomperz sees in his theory of the apperception of the senses, which worked through different sized and different shaped pores by selecting the fit from variously proportioned flying molecules, the counterpart of the childish theory of Ehrlich, which so captivated the imagination of American laboratories before the war, and which has been so helpful to us in serology, though such an ancient theory supported by such a modern theory has no claim to reality. But is it chance, which by the way Empedocles regarded paradoxically as the result of the action of certain laws of chaos, is it "chance" which directed two groping minds, twenty-five hundred years apart, into like channels of mental progress?

The doctrine of Spencer, an internal homogeneity becoming external heterogeneity, in the course of evolution, had its counterpart in the philosophy of the old Sicilian, though he apparently was haunted by the thought that there comes a time when the process is reversed and out of heterogeneity homogeneity again springs. Indeed it seems impossible to preserve the indestructibility of energy or matter in stellar space, unless we conceive of some cold storage for the flying emanations until they are again warmed into life, as Very[5] realizes in drawing attention to the wastage of stellar substance.

[5]Very, F. W. The Wasting of Stellar Substance. Scientia, 1-IV-1920.

PERFECT AND AMICABLE NUMBERS

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THE two types of numbers in our title have had a continuous history extending from the early Greeks to date, and may be justly called the most human of all numbers. To them were early attributed certain social qualities, and later also ethical import, while mystics of the middle ages believed that they possessed special powers as talismans. Continuously for twenty centuries a wide-spread interest has been taken in the purely numerical questions and puzzle problems which arose in the study of these remarkable numbers. We shall present here the more essential facts and fancies in the quaint history of these most human of all numbers.

A perfect number is one which equals the sum of its aliquot divisors, i. e., divisors which are less than the number itself. Thus 6 is a perfect number, being equal to the sum of 1, 2 and 3. The Pythagoreans called the perfect number 6 marriage "on account of the integrity of its parts and the agreement existing in it." In his *De Nuptiis Philologiae*, Martiano Capella stated that the perfect number 6 is attributed to Venus; for, it is made by the union of the two sexes, that is from triad, which is male since it is odd, and from diad, which is feminine since it is even.

To understand a later allusion, we need the definitions given by Nicomachus (about 100 A. D.) that 12 is an abundant number since the sum 16 of its aliquot divisors exceeds 12, while 8 is a deficient number since the sum 7 of its aliquot divisors is less than 8. He remarked that perfect numbers are between excess and deficiency, as consonant sound between acuter and graver sounds. In his *De Civitate Dei*, Aurelius Augustinus (354-430 A. D.) remarked that, 6 being the first perfect number, God effected the creation in 6 days rather than at once, since the perfection of the work is signified by the number 6. Alcuin (735-804), of York and Tours, added the remark that the second origin of the human race arose from the deficient number 8; indeed, in Noah's ark there were 8 souls from which sprung the entire human race, showing that the second origin was more imperfect than the first, which was made according to the perfect number 6. Rabbi Josef b. Jehuda Ankin, at the end of the twelfth century, recommended the study of perfect numbers in the program of education laid out in his book *Healing of Souls*. We shall return presently to the history of the arithmetical study of perfect numbers.

Two numbers, like 220 and 284, are called amicable if each equals the sum of the aliquot divisors of the other. Iamblichus states that Pythagoras remarked that the aliquot parts [divisors] of each of the numbers 220 and 284 have the power to generate the other, according to the rule of friendship; and that, when asked what is a friend, he replied "another I," which is shown in these numbers. According to Rau Nachshon (ninth century A. D.), Jacob prepared wisely his present to Esau of 200 she-goats and 20 he-goats, 200 ewes and 20 rams (Genesis, xxxii, 14), since this number 220 of goats is a hidden secret, being one of a pair of numbers such that the parts of it are equal to the other one 284, and conversely; and Jacob had this in mind; this has been tried by the ancients in securing the love of kings and dignatories.

Ibn Khaldoun related that "persons who have concerned themselves with talismans affirm that the amicable numbers 220 and 284 have an influence to establish a union or close friendship between two individuals. To this end a theme is prepared for each individual, one during the ascendency of Venus, when that planet is in its exaltation and presents to the moon an aspect of love or benevolence; for the second theme, the ascendency should be in the seventh. On each of the themes is written one of the specified numbers, the greater being attributed to the person whose friendship is sought." The Arab el-Magriti of Madrid (who died in 1007) related that he had put to the test the erotic effect of "giving anyone the smaller number 220 to eat, and himself eating the larger number 284."

The writer verified a few years ago that the only pairs of amicable numbers in which the smaller number does not exceed 6232 are 220 and 284, 1184 and 1210, 2620 and 2924, 5020 and 5564, 6232 and 6368. The second pair was discovered in 1866 by N. Paganini at the age of 16. It was missed by Euler, who in 1750 made the chief investigation of amicable numbers and listed 62 pairs. It would be easy, but not very interesting, to obtain further pairs, by the methods explained by Euler, by employing a table of prime numbers extending beyond the limit 100,000 of the table accessible to him. A prime number is one, like 2, 3, 5, 7, 11, which has no divisor other than itself and unity.

Let us return to perfect numbers and consider the main facts in their arithmetical history. We shall write 2^3 for 8 and 2^p for the product of p factors 2.

In his famous Greek text on geometry, Euclid proved that $2^{p-1}(2^p-1)$ is a perfect number if 2^p-1 is a prime. For $p=2, 3, 5, 7$, the values of 2^p-1 are 3, 7, 31, 127, which are all primes, so that 6, 28, 496 and 8126 are perfect numbers. These four numbers were mentioned explicitly by Nicomachus, who noted that they are the only perfect numbers in the respective intervals between 1, 10, 100, 1000

and 10,000. The last fact was twisted by Iamblichus (about 283-330 A. D.) and many later writers into the erroneous conclusion that there exists one and only one perfect number between any two successive powers of 10.

The fifth perfect number 33,550,336 was first given in 1456 in the manuscript Codex lat. Monacensis 14908; it corresponds to the value 13 of p in Euclid's formula. Many writers listed false perfect numbers, due to their belief that 2^p-1 is a prime for every value of p which is odd (i. e., not even). But Regius, in his Arithmetic printed at Strasbourg in 1536, noted that $2^9-1=511=7\cdot73$ and $2^{11}-1=2047=23\cdot89$ are not primes, while $2^{13}-1=8191$ is a prime and leads to the above fifth perfect number.

Cataldi, who founded at Bologna the most ancient known academy of mathematics, verified in 1603 that $2^{17}-1=131,071$ and $2^{19}-1$ are primes by the unnecessarily laborious work of trying as possible divisors each prime less than their respective square roots. He therefore concluded correctly that the sixth and seventh perfect numbers are $2^{16}(2^{17}-1)=8,589,869,056$ and $2^{18}(2^{19}-1)$. But he stated erroneously that 2^p-1 is a prime when $p=23$, 29 and 37. In fact, Fermat noted in 1640 that $2^{23}-1$ has the factor 47, and $2^{37}-1$ the factor 223, while Euler observed in 1732 that $2^{29}-1$ has the factor 1103. These errors cast doubt on the validity of Cataldi's claim that $2^{31}-1$ is a prime.

Fermat, who was a member of the parliament of Toulouse and an arithmetician of the highest ability, stated in 1640 the important fact that if p is a prime, 2^p-1 is divisible by no primes other than those of the form $2kp+1$. Hence if $2^{31}-1$ were not a prime each of its prime factors would be of the form of $62k+1$, so that it is unnecessary to consider most of the trial divisors tested by Cataldi. We shall see below that Euler knew a general principle which eliminates half of the trial divisors required by Fermat's rule. Closely related to all these facts is the second proposition stated by Fermat that, if q is an odd prime, $2^{q-1}-1$ is divisible by q, and his generalization that if q is any prime and n is any whole number not divisible by q, then $n^{q-1}-1$ is divisible by q. This result, which is the basis of the modern theory of numbers, is known as Fermat's theorem.

Mersenne, who acted as intermediary in the extensive correspondence between Fermat, Frenicle, Descartes, and other expert arithmeticians, quoted various arithmetical results due to them in his curious books, *Harmonie Universelle*, *Cogitata Physico Mathematica*, etc., published in 1634-1647. But when he made the oft-quoted statement that the first eleven perfect numbers are given by $2^{p-1}(2^p-1)$ for $p=2$, 3, 5, 7, 13, 17, 19, 31, 67, 127, and 257, he was relying only in part upon more modest facts communicated to him by his able correspond-

ents, but mainly upon some unlucky personal guessing as to the hidden mystery of prime numbers. He pretended to know that the number $2^{127}-1$ of 39 figures is a prime, that the number $2^{257}-1$ (which exceeds the square of the preceding vast number) is a prime, and that all of the intermediate numbers 2^p-1 are composite,—and yet he admitted that "to tell if a given number of 15 or 20 figures is prime or not, all time would not suffice for the test, whatever use is made of what is already known." More than two centuries later it was shown that Mersenne erred at least in including $p=67$ in his list and in excluding the values 61, 89 and 107 of p. The fact that $2^{67}-1$ is composite was proved by Lucas in 1876, while its actual factors were found by Cole in 1903. The fact that $2^{61}-1$, a number of 19 figures, is a prime was proved independently by Pervusin in 1883, Seelhoff in 1886, Hudelot in 1887, and Cole in 1903. Both Powers and Fauquembergue proved in 1911-1914 that $2^{89}-1$ and $2^{107}-1$ are primes. It is not surprising that Mersenne's guesses were erroneous, but it is quite surprising that his errors have been detected, thanks to the powerful modern methods of testing whether or not 2^p-1 is a prime.

Euler, one of the greatest mathematicians of all ages, proved in 1732 that, if $p=4n-1$ and $8n-1$ are primes, 2^p-1 has the factor $8n-1$, so that 2^p-1 is not a prime when $p=11, 23, 83, 131, 179, 191, 239, 251$, etc. He noted that $2^{43}-1$ has the factor 431 and that $2^{73}-1$ has the factor 439. In 1741 he found that $2^{47}-1$ has the factor 2351, a case which had earlier deceived him. In 1772 he proved that $2^{31}-1$ is a prime. According to Fermat's result, every prime factor p is of the form $62k+1$. But p divides $2\,(2^{31}-1)=a^2-2$, where $a=2^{16}$, and Euler knew that every prime which divides any number of this form a^2-2 is of one of the forms $8n+1$, $8n+7$. Hence in $p=62k+1$, k must be of the form $4m$ or $4m+1$. Euler therefore considered only the possible prime factors of the form $248m+1$ or $248m+63$.

In 1877 Lucas proved that $A=2^{127}-1$ is a prime by a powerful new method. For so great a number (of 39 figures), it is clearly impracticable to test directly all the primes $2\cdot127\,k+1$ as possible factors, or even the half of them under Euler's simplification of Fermat's method. Instead, we use the recurring series 1, 1, 2, 3, 5, 8, 13, ____, which Leonardo Pisano had first employed in 1202 to find the number of offspring of a pair of rabbits. Each term of this series equals the sum of the preceding two terms. Write u_k for the kth term. One of Lucas's tests for primality applies to numbers having the remainder 3 or 7 when divided by 10. Since $2^5=32$ has the same remainder as 2, we may suppress multiples of 4 in the exponent of a power of 2 when finding the remainder on division by 10. Hence the remainder from our A is $2^3-1=7$. Writing $k=2^n$, Lucas verified that 127 is the

least positive whole number n such that u_k is divisible by A; hence A is a prime by his test. Similar tests for primality due to Lucas were used by Fauquembergue and Powers independently in 1914-1917 to prove that $2^{89}-1$ and $2^{107}-1$ are primes and that 2^p-1 is not prime when $p=101, 103, 109$, the actual factors not being found.

The further known results are exhibited in the following table which gives the least prime factor of 2^p-1 for the various primes p, and the name of the discoverer of the factor and the date:

p	Factor	Discoverer	p	Factor	Discoverer
41	13367	Plana, 1863	151	18121	LeLasseur, 1881
53	6361	Landry, 1869	163	150287	Cunningham, 1908
59	179951	Landry, 1869	173	730753	Cunningham, 1912
71	228479	Cunningham, 1909	181	43441	Woodall, 1911
79	2687	Reuschle, 1856	197	7487	Cunningham, 1895
97	11447	LeLasseur, 1881	211	15193	LeLasseur, 1881
113	3391	Reuschle, 1856	223	18287	LeLasseur, 1881
			233	1399	Reuschle, 1856

To summarize the results quoted above, 2^p-1 is known to be composite for thirty-two of the primes $p<257$, but to be a prime and hence to lead to a perfect number $2^{p-1}(2^p-1)$ for the following twelve values: $p=2, 3, 5, 7, 13, 17, 19, 31, 61, 89, 107, 127$. Hence only the following eleven values now remain in doubt: $p=137, 139, 149, 157, 167, 193, 199, 227, 229, 241, 257$.

All that precedes relates to perfect numbers which are given by Euclid's formula $2^{p-1}(2^p-1)$. Is every perfect number of this form? In 1638 Descartes stated that he could prove that every even perfect number is given by Euclid's formula. By far the simplest proof is that published by the writer in 1910. Let 2^nq be an even perfect number, where q is odd. All the divisors of 2^nq are obtained by multiplying each of the divisors $2^n, 2^{n-1}, \ldots, 2, 1$ of 2^n by each of the divisors of q. Hence the sum of the divisors of 2^nq is ms, where $m=2^n+\ldots+2+1$ and s is the sum of the divisors of q. If we multiply m by 2—1, we see that all but two terms of the product cancel, so that $m=2^{n+1}-1$. By definition, a perfect number equals the sum of all its divisors other than itself, whence

$$2^nq=ms-2^nq, \qquad 2^{n+1}q=ms=(2^{n+1}-1)s.$$

Dividing by $2^{n+1}-1$, we get $s=q+d$, where $d=q/(2^{n+1}-1)$. Thus the whole number $d=s-q$ is a divisor of q. Since the sum s of all the divisors of q reduces to $q+d$, q and d are the only divisors of q, so that $d=1$ and q is a prime. From $d=1$, we get $q=2^{n+1}-1$. Hence every even perfect number 2^nq is of Euclid's type.

Whether or not there exists an odd perfect number has never been decided. If one exists, it must be of the form ps^2, where p is a prime,

as noted by Descartes in 1638. Frenicle observed in 1657 that p must be of the form $4n+1$. Sylvester proved in 1888 that no odd perfect number has fewer than six distinct prime factors, nor fewer than eight unless it be divisible by 3.

A multiply perfect number, like 120 or 30240, is one the sum $3\cdot120$ or $4\cdot30240$ of whose divisors equals an exact multiple of the number. Such numbers, mostly very large, were found by Mersenne, Fermat, Frenicle, and Descartes in the years 1631-1647.

To obtain an interesting generalization of both perfect and amicable numbers, let n_1 denote the sum of the divisors $< n$ of n, let n_2 denote the sum of the divisors $< n_1$ of n_1, etc. In case n is a perfect number, $n=n_1=n_2=\cdots$, and conversely. If $n_2= n$, then n and n_1 are amicable numbers. If $n_k=n$, the chain of numbers $n, n_1, n_2, \cdots$ is said to be of period k. In 1913 the writer proved that there exists no chain of period 3, 4, 5 or 6 with $n<6233$, and verified for an extensive set of values of n that any non-periodic chain contains a prime, so that the next term is unity. By a more extended search, Poulet discovered in 1918 the following chain of period 5:

$$n=12496=2^4\cdot11\cdot71,\ n_1=2^4\cdot19\cdot47,\ n_2=2^4\cdot967,$$
$$n_3=2^3\cdot23\cdot79,\ n_4=2^3\cdot1783,\ n_5=n,$$

and noted that 14316 leads a chain of 28 terms.

The writer defined an amicable triple to be three numbers such that the sum of the aliquot divisors of each equals the sum of the remaining two numbers, and obtained the following two examples of amicable triples formed of distinct numbers:

$$3\cdot89b,\ 11\cdot29b,\ 359b \qquad (b=2^{14}\cdot5\cdot19\cdot31\cdot151);$$
$$293\cdot337c,\ 5\cdot16561c,\ 99371c \quad (c=2^5\cdot3\cdot13).$$

Lionnet defined a perfect number of the second kind to be a number which equals the product of its aliquot divisors. But the only such numbers are p^3 and pq, where p and q are distinct primes, and the question is too simple to be amusing.

In 1657 Fermat challenged the English arithmeticians to find a cube (other than 1 and 7^3) which when increased by the sum of its aliquot divisors becomes a square. The least answer appears to be the cube of $2\cdot3\cdot5\cdot13\cdot41\cdot47$, the sum of whose divisors is the square of $2^7\cdot3^2\cdot5^2\cdot7\times13\cdot17\cdot29$. He also demanded a square which when increased by the sum of its aliquot divisors becomes a cube; the simplest know answer is the square of $43098=2\cdot3\cdot11\cdot653$, the sum of whose divisors is the cube of $1729=7\cdot13\cdot19$. John Wallis found more complicated solutions of each problem by a very long computation.

For complete references to the literature on the present subjects see the writer's *History of the Theory of Numbers*, Carnegie Institution of Washington, Vol. I, 1919, pp. 1-58, 393-407.

CLIMATE AND HEALTH, WITH SPECIAL REFERENCE TO THE UNITED STATES[1]

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Present Views Regarding the Relations of Climate and Health

THE modern view as to the part played by climate in relation to health is very different from that held in earlier days. The cause of most diseases was formerly sought directly in atmospheric conditions. These conditions, to state the present view very broadly, are now believed to be important in two ways. They may affect, more or less directly, the life, development and virulence of the micro-organisms which are the specific cause of disease, and they may strengthen or weaken the individual's power of resistance against the attacks of these organisms. The older views concerning the predominant and direct influence of climate have largely been replaced by the conviction that good hygiene is more important than climate alone, and that, in the matter of the influence of a change of climate as a preventive or restorative, a change of residence, habits, occupations, food, is usually of as much importance as, if not of more importance than, the actual change in atmospheric conditions. If pure air, good food, freedom from worry, time for rest, proper exercise, outdoor life and a congenial occupation are provided, many bodily and mental ailments yield to the treatment. Climate is by no means to be discarded as of no account. It affects our physical and mental condition and our bodily comfort. It may be dull, rainy and cheerless, or bright, sunny and exhilarating. It may tend to keep us indoors, or it may naturally tempt us to go out. Thus some climates are naturally avoided; others are sought out. The choice of a suitable climate must depend upon the disease to be dealt with and upon the individual concerned.

What is a Good Climate?

What, then, is a "good climate?" This question can here be answered only in the most general way. The answer, in individual cases, must obviously depend upon a person's physical and mental condition; upon his own personal preferences, and upon the factors other than climate which should be taken into account in each special

[1]Part of a Presidential Address before the American Meteorological Society, Chicago, Ill., December 29, 1920. The writer is indebted to Dr. Guy Hinsdale, of Hot Springs, Va., for valued criticisms.

case. A "good climate" is naturally one which is favorable to the development of a sturdy race of men and women, physically strong and mentally alert. There is a pretty general agreement, among physicians, physiologists and climatologists, that, excepting those who are distinctly ill, the best climate for most people and most of the time is one which has frequent moderate weather changes; fairly marked annual and diurnal variations in temperature; a reasonable amount of cold during at least part of the year; a refreshing variety in the amount of cloudiness, and sufficient rainfall to provide enough moisture for the growth of grass and crops. Such a climate is an intermediate one. It is neither invariably hot nor permanently cold. It is neither monotonously arid and cloudless, nor always dull and rainy. It is between all extremes. The climates of much of the so-called "temperate zones" are of this general type. Their physiological effects are intermediate between those of the equatorial and those of the polar zones. They exercise the body's power of reaction and adaptation, keeping it physiologically active, and in good "working condition," without subjecting the different organs to too severe a strain.[2]

A climate which encourages people to spend the maximum possible amount of their time outdoors, in the open air, is, other things being equal, the best for the majority of men and women. Applying these general principles to the question of health, it may be stated that a health resort where a patient can find comfortable quarters, congenial company, plenty of diversion, and where favorable climatic conditions such as those above noted, with abundant sunshine, an absence of disagreeable winds and dust and of sudden marked weather changes, encourage outdoor life, is to be recommended. The climate does not necessarily and inevitably cure, but it is very often an important help in the treatment of disease. To quote Sir H. Weber, "for any given class of cases, that climate is a good one in which the qualities that would be disadvantageous are to a certain degree absent during the whole year, or at least part of the year, while the other qualities are present by the proper use of which the bodily strength is raised and the restoration of the affected organs and functions is facilitated."

Is There Any "Perfect" Climate?

In the foregoing quotation from one of the leading medical climatologists, emphasis is laid on one point concerning which there is a general and persistent misconception. "That climate is a good one," Sir H. Weber wrote, "in which the qualities that would be disadvantageous are to a certain degree absent during the whole year, or at least part of the year." In other words, a good climate has the fewest

[2]F. P. Weber and G. Hinsdale, "A System of Physiologic Therapeutics," Philadelphia, 1901, Vol. III, p. 18.

"outs," or is free from its "outs" during a portion of the year. It is often said that the climate of a certain place is "perfect" or "ideal." As a matter of fact, there is no such thing as a "perfect" climate, anywhere, or all the time. Every climate has some disagreeable features. Health resorts are never equally desirable at all seasons. It is probably safe to say that every climate has advantages of its own for some special purpose, but some climates have more, and some have fewer, disadvantages. A southern climate which has a mild and genial "winter," and therefore provides abundant opportunities for an outdoor life at that season, is likely to be too hot, or rainy, or dusty, in summer. A northern climate, which has the advantages of cool summers, is likely to be very cold and stormy and snowy in winter. A western seacoast in subtropical latitudes, with the attractions of equable temperatures, mild winters and cool summers, relatively small rainfall and few stormy days, may be too damp and too foggy for many invalids. Mountain resorts, often so useful in the treatment of lung diseases, may have the disadvantages of being too cool at night; too windy and dusty by day, or of having frequent severe local storms. "Perfect" climates, then, do not exist. In climatotherapy, which may be broadly defined as the use of climate for checking or preventing the development of disease, and for aiding the recovery of those who are ill or convalescent, the obvious course is to select a locality where the other necessary conditions, such as suitable accommodations, good food, expert medical attendance, and so on, are already provided, and where the climate has a maximum of the desired characteristics for the particular case concerned, and the minimum of undesirable features. The seeker after health whose physician orders a "change of climate" should go away expecting some conditions which are neither "perfect," nor perhaps even altogether agreeable. If a "perfect" climate is not anticipated, the inevitable lack of perfection will bring with it no disappointment. It should be remembered that any climate which is recommended by a competent physician doubtless has far more good qualities than bad ones. The utmost advantage can always be taken of the good; most of the temporary disagreeable ones can be escaped by staying indoors, and by maintaining a cheerful disposition which refuses to be overcome by an occurrence of so little importance as an occasional spell of bad weather.

No Climate is "The Only Climate" For Any Individual Case of Ill Health

In connection with this misconception regarding the existence of "perfect" climates, there is a widespread and persistent popular impression that certain climates have such special and peculiar properties of their own that there is some one particular climate which is the only one fitted for a special case of illness. If an invalid hits upon

this climate, he believes that he will, beyond a doubt, regain his health.

In my own experience of a score of years I have had abundant and often very distressing opportunity to learn how widespread is this notion, and how nerve-racking, in many people's minds, the choice of this one climate becomes. I have received many letters, personal visits and even telephone calls, asking me to name that special place whose climate is the one needed in the individual case concerning which the inquiry is made. It is hardly necessary for me to say that under no circumstances do I attempt—nor should any climatologist attempt—to prescribe any climate for any specific disease. That is the responsibility of the physician. The most pathetic case which has ever come to my own attention was that described in a letter which I received a few years ago. The letter was from a physician in New York State, who had a son seriously ill with a complication of disorders. Leading specialists in New York had been consulted, but the youth was steadily growing worse, and there seemed little hope of saving his life. Evidently in depair, and as a last resort, the father, who was unknown to me even by name, wrote to me, giving me full details as to his son's illness and the previous treatment of the disease, and asked me to name the place to which the son could be taken in order to give him the benefit of whatever climate, in my judgment, would be the suitable one for that particular case. That letter revealed the whole story of the father's love for his boy; the tragedy of his despair of saving the boy's life; the grasping at a "last straw" in his writing to me as one of whom he had somehow or other heard and who might possibly give the advice which would save the son's life. What could I write in reply to that father's pathetic and despairing appeal? All I could do was to write a letter as full of human sympathy as it was possible to make it; to urge consultation with some physician who had made a specialty of climatotherapy; to point out the importance of selecting some place where every possible comfort and care could be found, and then to mention the general advantages of the winter climates of a considerable number of Southern resorts where relief from the winter cold and from the sudden and severe weather changes of New York State might be found. I need not say that I named no place as possessing the one climate which would be of most help in the curative process. The end of this story I do not know. No second letter ever came to me from that father.

This incident serves as a striking illustration of exactly what I am here trying to emphasize. Climate, as a recent writer has well put it, may "play an important part in the curative process, but the climate of certain localities does not possess any peculiar properties which act as a specific on certain diseases." Or, as another has put it, "the choice of a climate is not a nerve-racking decision the entire success of which depends upon hitting upon the one ideal climate in the whole

world, but simply the selecting of one out of six or seven localities, any one of which will do all that climate can do to restore health" (Dr. Woods Hutchinson).

Local Versus General Climates

This belief that the climates of individual health resorts possess certain special local characteristics, of peculiar health-giving value, and differing essentially from the general climate of the surrounding country, is apparently largely based upon an exaggerated idea of the importance of local controls over climate. The subject of local as compared with general climates is a large one, and cannot here be adequately discussed. A few illustrations may, however, be given to indicate some typical cases.

As a whole, climates are more alike than unlike. In the Tropics, where cyclonic weather controls are characteristically absent (except in certain restricted areas and at certain special seasons), and where diurnal controls are dominant, a small district well enclosed by mountains probably comes as near to having a local climate as is possible on a land area. Here the general winds, which are the most effective agents in wiping out climatic boundaries, are excluded, and temperature, winds, cloudiness, humidity, rainfall and other elements are essentially influenced by local conditions. Over most of the "Temperate Zones," on the other hand, where cyclonic cloud and rain areas, and cyclonic winds, are the characteristic phenomena of the weather, and largely determine the character of the climates, local controls inevitably have far less influence. Examples of various degrees of local modifications of climate may be classified under three general heads: (1) extended, open, level plains, lacking bodies of water and forest cover; (2) coasts; (3) mountains. To these may perhaps be added (4) the subordinate and very local influences of forests. In the first-named districts, where the prevailing winds have free sweep, and where there are no local topographic, water or forest controls, local climates, in any real sense, cannot exist. In the second case (2), that of coasts, places on and near the seashore often have the advantage of a cooling sea-breeze on hot summer days. The effect of the water is noticed on a much larger scale, and to a far greater distance inland, when the prevailing winds, or the temporary cyclonic winds, happen to blow on-shore. The proximity of the ocean, or of large inland bodies of water like the Great Lakes, may have considerable effects not only upon temperature, but also upon cloudiness, humidity, rain and snowfall. Marine fogs are another local characteristic of some seacoasts. (3) Topography is one of the chief controls in modifying general climates. Elevated stations have certain distinguishing characteristics which, when well developed, give rise to the term "mountain climate." Altitude, as is well known, affects temperature. Mountain stations as

a rule have lower temperatures than adjacent valleys and lowlands. On the other hand, on clear, quiet nights, especially in winter, "inversions of temperature" frequently give slopes and summits distinctly milder spells than those found at lower levels. Mountains and even low hills modify the direction of the winds. A range of mountains, or a single mountain, may protect places to leeward against strong winds. Cool, descending nocturnal breezes, following hot summer days, often provide comfortably refreshing nights where houses are favorably situated opposite the mouths of valleys. Proper choice of building sites, above the level of valley and lowland fogs, ensures drier air and more sunshine than are found lower down in the fog zone. Mountains offer opportunities for the development of diurnal cumulus clouds on fine summer days, and local showers and thunderstorms occur with greater frequency in mountainous country than over the surrounding lowlands. (4) Forests, although very subordinate controls of local climate, check wind velocity, serving as a protection against disagreeably strong, hot or cold winds; provide fresh, clean, pure air, very free of dust and of injurious micro-organisms; slightly lower the mean temperature and slightly increase the relative humidity. The air in pine forests has long been believed to have certain desirable soothing and healing properties, of benefit in affections of the nose, throat and lungs. It is upon such local characteristics as those here mentioned, and others like them, that many local weather prognostics and proverbs are based. Familiarity with such weather signs often gives local "weather-wise" people some advantage over an "official" forecaster at a great distance, who has only the general conditions shown on the weather map to guide him.

In these, and in other ways, general climates may locally be more or less modified. But the larger controls of the general climate persist. What are popularly believed to be special peculiar qualities of the local climates of well-known health resorts are usually in no way essentially different from the climates of hundreds or thousands of square miles of the surrounding country. The factors which are of most consequence in giving such resorts their reputation are not, therefore, the special and peculiar qualities of their *local* climates, although these may play a part, but the combination of many conditions which render these places safe, desirable and agreeable residences for invalids and for pleasure-seekers.

Factors Other Than Climate Which Determine the Popularity of Health Resorts

When, centuries ago, Hippocrates wrote "in chronic diseases it is advisable to go to another country" he doubtless had in mind the benefits to be derived not only from a change in climate but also from a change in the general environment, social, mental and physical. For

it cannot be too strongly emphasized that climate is but one element in the treatment, albeit often a, or even the, most important element. In fact, so large a part do the other factors play that it is difficult, even impossible, to determine how much of the benefit of a health resort is derived from the climate, and how much from other conditions. Given a suitable climate for the particular illness in question, among the other important contributing factors are accessibility; comfortable and cheerful accommodations; an altered diet of good food; expert medical attendance and proper hygiene; a congenial social environment; outdoor attractions of beautiful scenery, opportunity for varied forms of exercise and diversion such as walks, drives, seabathing, outdoor sports, and the like. Rest; recreation; freedom from worry; mental and social change and relaxation, usually play an important part in the benefit derived from what is generally called merely a "change of climate," and as a rule accomplish better and quicker results than a more prolonged treatment at home. The use of suitable mineral waters, taken internally or used for bathing purposes, is another non-climatic element which, in the case of some resorts, is of predominant importance in the treatment.

The enumeration of these various non-climatic elements should by no means lead to the conclusion that climate is of no value, that there is no such thing as climatotherapy; that climatologists have no concern in this matter. Climate, it is true, is but one element in the treatment, but it is an element of great, and in most cases of paramount, importance. As has already been pointed out, atmospheric conditions are critical in that they affect the micro-organisms which are the specific causes of disease; they strengthen or weaken the individual's power of resistance; they encourage or they discourage rest and recreation out of doors, and outdoors is the best treatment of all.

The established health resorts of the United States, and of other countries, have gained their reputation because they combine, more or less completely, the complex series of factors just enumerated. They have what has well been termed "the momentum of an early start." Advertising has had, and always will have, a great deal to do with the popularity of all such resorts. So far as climate alone is concerned, there are enoromus vacant tracts in this country—in the Appalachians, in the Rocky Mountains and plateaus; on the Pacific slope—where health resorts without number could be developed with just as favorable climatic conditions as those which prevail at the resorts which are already established. But the latter now have the accommodations and the other advantages which are needed to make them popular, and therefore they have the "early start."

In what has thus far been said, the term health resorts has been exclusively used because the subject under discussion concerns itself primarily with the climatic treatment of disease. It is however, per-

fectly obvious that most of the so-called health resorts are also pleasure resorts, frequented by persons who are in no way ill, however much they may sometimes seek to give themselves, and others, the impression that they are so, but who are attracted by the many natural and artificial advantages which these so-called health resorts offer. There are, in reality, few places which are frequented solely by invalids. Those which belong in this group are sanitaria where special attention is paid to the treatment of certain special diseases, and where no one is admitted who is not in need of such treatment. Many places which began as health resorts have now become pleasure resorts, pure and simple. Others are rapidly going through the same change. It is, therefore, impracticable, in the present discussion at any rate, to draw any distinction between resorts which are devoted solely to health purposes, and those which are used partly or solely for pleasure.

The Health Resorts of the United States: General

Having now considered, in broad outline, the larger relations of climatotherapy, attention may next be directed more specifically to the health and pleasure resorts of the United States. This phase of the question is also treated in a very broad way. No attempt is here made to give a catalogue of the health resorts of the United States, or to include any numerical or statistical data. All such data can readily be secured from the regular publications of the United States Weather Bureau. All that is here intended is to give a systematic presentation of the larger climatic characteristics, in the form of broad generalization, in such a way that the essential facts may be properly coördinated. Furthermore, it does not fall within the scope of the present discussion to consider in detail the physiological reactions of the human body to varying meteorological conditions, nor to mention any but the most common and most familiarly known diseases.

In what follows, the places which are specifically mentioned by name are considered as types of the health and pleasure resorts which are already established in the same general regions, and may be taken also as representative of many others which may, in the future, be established in the same districts, and with similar advantages in so far as these concern the climate and the general physical environment.

The Climatic Provinces of the United States in Relation to Health

For purposes of systematic coördination it is necessary to group the health resorts of the United States in certain large and easily remembered climatic provinces. These are: (1) the Eastern Province, extending from the eastern base of the Rock Mountains to the Atlantic Ocean on the east and the Gulf of Mexico on the south; (2) the Rocky Mountain and Plateau Province, and (3) the Pacific Province.

The Eastern Province. General Relations to Health

From the point of view of health, the most important climatic features of the Eastern Province are the great seasonal ranges of temperature, the severe cold of the winters over northern sections being followed by hot summers, and the suddenness, frequency and amount of the weather changes, especially in winter. Several short periods of extreme cold are to be looked for every winter, and the summers always bring spells of extreme heat. In such a region, where sudden severe and irregular weather changes are so characteristic, climatic averages can give little idea of the actual conditions which are experienced from day to day. Seasons often differ markedly in character from year to year. Weather changes are erratic and unexpected. It has become a popular saying that almost any kind of weather may be expected at any time of the year. The Appalachians are of too moderate an elevation to produce typical mountain climates, and the effect of the ocean is reduced to a minimum because the prevailing winds are off-shore. Lorin Blodget was not far wrong when he wrote: "We scarcely regard the Alleghenies as disturbers of any condition of climate except in the moderate degree produced by altitude alone."[3]

With decreasing latitude, the southern tier of States has distinctly milder winters, with less and less snowfall, somewhat warmer summers, and generally steadier and more "settled" weather.

The severe weather changes of the northern winters are usually borne without serious discomfort or harm if the body is in good health, and accustomed to adjusting itself quickly. Cold in itself, if not too severe and not too long continued, is beneficial to most people who were born and who have lived in the higher latitudes, for it necessitates increased bodily heat production and metabolism, and leads to a beneficial activity of many tissues and organs. On the other hand, these same sudden physiological readjustments may be too severe a strain on the aged and those who, because of illness or general physical disability, cannot react readily. Such meteorological conditions may then bring on various functional disturbances, and are especially harmful in the case of elderly people.

In damp air, evaporation from the internal surfaces of the body is decreased. When the air is at the same time cold, the lungs and respiratory passages not only lose a large number of heat units in the effort to heat the inspired air up to the body temperature, but also lose much moisture by evaporation, warm air having a greater capacity for water vapor than cold air. These physical processes, and the frequency of the sudden readjustments necessitated by the variable weather changes, are often followed by certain well recognized conditions of ill health. Diseases of the organs of respiration are prevalent in the

[3]Lorin Blodget: "Climatology of the United States," 1857.

winter months over the northern and northeastern sections, where the winter cold is often damp, and where temperature and humidity changes are most marked. Such diseases are "colds," influenza, bronchitis, catarrh, whooping cough, diphtheria, congestion of the lungs, pneumonia, and so on. The outdoor conditions tend to lower the vitality of the body which is not in good physical condition, and, when unusually severe or long continued, may react unfavorably on those who are otherwise in good health. Furthermore, the indoor life which so generally results from the prevalence of cold and of stormy weather, and the consequent lack of fresh air, naturally lead to a general lowering of the vitality, and to a diminished power of resistance against the attacks of disease germs. The greatest prevalence of most of the throat and lung diseases towards the end of the winter and in early spring depends upon the fact that the injurious effects of an indoor life, insufficient exercise in the open air, and inadequate ventilation, are at a maximum after several weeks or months of that highly artificial "hot-house" sort of life. Diseases of the nervous and circulatory systems, and rheumatism are also common in this type of winter climate. In summer hot spells, when both temperature and relative humidity are high, diarrhoeal disorders become frequent; sunstroke and heat prostrations occur. Hay fever is also a summer condition which affects large numbers of people who, on this account, seek places from which the irritating cause is absent.

The Health and Pleasure Resorts of the Eastern Province: General Classification

The simplest rough-and-ready grouping of the health and pleasure resorts of the eastern United States depends upon the fact that the northern winters are cold and stormy, and that the summer temperatures are high, especially in the south. It is thus to be expected that great numbers of invalids, and of others who are in a position to travel, should seek relief from the inclemency of the winter months by going south, and should go north, to cooler latitudes, during the hottest season. There is, therefore, a general group of I. *Southern winter resorts*, further roughly subdivisible into (a) mountain, (b) coast, and (c) intermediate. Likewise, there is a general group of II. *Northern summer resorts*, also subdivisible into (a) mountain, (b) coast, and (c) intermediate. No classification of this sort can be a hard and fast one. Many of the southern resorts which are frequented by Northerners who are trying to escape the cold in winter are used by Southerners who find these same places desirable resorts during the summer. Further, physicians are sending certain classes of cases to northern resorts, like the Adirondacks, in winter, and it is becoming more and more the habit of some of the younger and more robust members of the population of the northeastern cities to enjoy winter

outings in the mountains of New England, and in the Adirondacks, where the deep snows give opportunity for winter sports, such as snowshoeing, skiing and tobogganing. Again, a good many readily accessible places in intermediate latitudes, such, e. g., as Atlantic City, N. J., are well filled at all seasons.

Southern Winter Resorts

Southern winter resorts have long been recommended by physicians who realize the advantage of a winter sojourn for many invalids and convalescents in climates where the conditions are less rigorous than those farther north, and are therefore also better suited to an open-air life. The best-known Southern health resorts are in Virginia, the Carolinas, Georgia and Florida. In mid and late winter and early spring a great exodus of health-seekers, bound south, sets in. Luxurious trains, equipped with every luxury and comfort, with through Pullman cars to all the Southern resorts, are then crowded to their utmost capacity. The development of this elaborate system of transportation, and of the great numbers of modern and highly luxurious southern hotels, is a natural response to the steepness of the winter poleward temperature gradient on the Atlantic coast.

The invalids who constitute a large element in this annual southern migration are sufferers from tuberculosis, asthma, bronchitis and other affections of the nose, throat, and lungs; from rheumatism; nervous and kidney troubles; insomnia; overwork. Convalescents from acute illnesses of many kinds make up a further considerable percentage of the total. But increasing numbers of those who "go South" in winter are really nothing but pleasure-seekers, afraid of the cold. They belong to the wealthy and semi-leisure classes, and are in search of a soft and comfortable life, with plenty of diversion and such outdoor occupations as golf, sea bathing and horseback riding. It is, perhaps, fortunate for the future race that so insignificant a part of the population as a whole can afford to bask in the warm sunshine of luxurious southern winter resorts.

Asheville, North Carolina, is probably the best known of the southern winter resorts of the mountain group (I, a). Far enough south to escape the extreme severity of the winter cold and storms, yet far enough north to have a moderately stimulating and invigorating climate, with many dry and sunny days; situated in the midst of a beautiful mountainous country, with excellent hotel accommodations and abundant opportunity for outdoor life and diversion, Asheville has become a resort for those afflicted with pulmonary and similar ailments; and for a large group of cases such as nervous disorders, for example, which are benefited by an intermediate climate. It is used by Northerners in winter and by Southerners in summer, the two chief seasons being February and March, and July and August.

The mountainous portions of Virginia, the Carolinas and Georgia offer essentially similar climatic advantages over enormous areas, and are certain to witness the development of many health and pleasure resorts in addition to those already established. A special class of stations in this same general region is that which has become known on account of its mineral springs, e. g., Hot Springs, Va., and White Sulphur Springs, W. Va. These places are chiefly resorted to because of the benefits to be derived from the use of the waters and from the expert medical practitioners whose services are there available, but they also have the advantages of a mild winter climate and excellent accommodations.

The southern coast resorts (I, b) may be considered to extend as far north as Virginia, and to include Florida and the Gulf coast on the south. The New Jersey coast is intermediate between the northern (II, b) and the southern (I, b) coasts, but here again no sharp line of demarkation by latitude can be drawn. Old Point Comfort, Newport News and Norfolk, Va., have long been winter and spring resorts for Northerners and have been used as summer resorts by people from the South. They combine the advantages of a mid-way location, accessibility, good hotels, and a climate moderated by ocean influences both in winter and in summer. The journey from the great northern cities to the far South being often somewhat trying to those in delicate health, these Virginia coast stations have proved convenient temporary stopping places, and also provide a gradual climatic transition between north and south.

Farther down the Atlantic seaboard, the advantages of the southern coast as a place for a winter sojourn naturally increase. Far to the south, at the extreme end of the Atlantic coast temperature-ladder, lies Florida, a deservedly famous winter playground and health resort whose popularity has grown very rapidly. The peninsula of Florida, lying between the warm waters of the Atlantic and the Gulf, enjoys an almost tropical climate, naturally attractive to those who come from the ice and snow of the northern states. The Florida "winters" are extraordinarily mild and equable, interrupted now and then by moderate cold spells which, on relatively infrequent occasions, are sufficiently severe to bring frost. Invalids should be prepared for these occasional cold spells, as well as for spells of enervating, even uncomfortable warmth, for there are many distinctly "hot" and relaxing days, especially in the late winter and spring. Abundant sunshine; a dry, sandy soil; relatively few rainy days; the absence of snow; a soft, balmy air; the beauties of the semi-tropical vegetation; every inducement to an outdoor life which natural conditions and the thought and ingenuity of man can devise; excellent train service; luxurious hotels and sea-bathing even in mid-winter—these are sufficient to ensure the popularity of Florida as a winter resort. Before the heat of later

spring begins, a wholesale exodus of invalids and of pleasure-seekers takes place. The northbound trains are then crowded, hotels are closed, and Florida settles down to the quiet of its long summer.

This mild, relatively damp climate is soothing and relaxing. It is prophylactic, preventive. While not the best for certain cases and stages of tuberculosis, and not unlikely to aggravate certain anemic conditions, Florida winters have many excellent qualities for convalescents; for elderly persons; for those broken down nervously; for many patients with nose and throat troubles, and in certain diseases of the digestive organs. Too long a sojourn in such a climate may, however, lead to a marked toning-down of the system, to loss of appetite, and to digestive and nervous difficulties. Palm Beach, with its seashore life, is known the country over through persistent newspaper notoriety. Tampa, Miami, Jacksonville, St. Augustine, are familiar names.

The Gulf coast, from northwestern Florida to Texas, by reason of its mild winters and its summers tempered by the prevailing onshore winds, offers numerous resorts which, while not as generally frequented by Northerners as those of the Atlantic seaboard, are popular among Southerners, both in summer and in winter. New Orleans, about midway on the Gulf coast, attracts Northern visitors who are diverted by the life of this quaint and picturesque city.

Between the Appalachian Mountains on the west and the Atlantic seaboard on the east, and towards the southern portion of the Atlantic Slope, there is an intermediate group of stations (I, c) of considerable importance. These are mostly situated at a very moderate elevation above sea-level, in a belt of dry, sandy, porous soil covered with extensive pine forests; far enough south to have dry, mild and relatively sunny winters, without the sudden weather changes of the north, yet with a more bracing climate than that of Florida. Aiken and Camden, S. C., Pinehurst and Southern Pines, N. C., Thomasville and Augusta, Ga., and other places, with excellent hotels, good golf links, and abundant attractions for an outdoor life, are much resorted to by Northern invalids and pleasure-seekers. The pure soothing "balsamic" air of the pine forests is doubtless a health asset whose exact value has yet to be determined. Pinehurst and Southern Pines are attractive names, with good "advertising value."

Northern Summer Resorts

One of the great summer vacation grounds of the United States is in New England and in the Adirondack area of New York. From the hot and crowded cities, vast throngs of people surge northward every summer, by train, steamboat and automobile, to the mountains, the seashore and the country, to seek relief from the summer's heat; to find rest and relaxation in beautiful scenery, changed surroundings and

pure air. This annual exodus is chiefly made up of the well-to-do classes, and consists proverbially mostly of women and children. The men are usually obliged to limit their vacations to "week-ends," or to short outings of a few weeks. The large majority of those who frequent these northeastern summer resorts are not invalids, in any true sense, but do want and need rest, an outdoor life and changed surroundings.

The mountain districts of the northeast—the White Mountains of New Hampshire, the Green Mountains of Vermont, the Berkshire Hills of Massachusetts, the Catskills and Adirondacks of New York (II, a)—have long been favorite summer pleasure resorts. The summer population is here many times greater than that of winter. Hotels, boarding houses, cottages, camps, are filled. These mountain regions have many attractions for the summer visitor. They abound in picturesque scenery. They offer innumerable varied excursions. Mountain climbing, camping, fishing, tennis, golf, appeal to thousands of people.

The specific climatic advantages of the mountains are found in their clean pure air, in their latitude, and in their elevation. There is relief from the more intense heat of the crowded cities farther south, the nights in the mountains being as a rule cool and refreshing. But during the general hot waves which prevail over large sections of the eastern United States at one time, and import heat from a distance in their southerly winds, the mountains are by no means exempt from high temperatures. Local topography often plays a considerable part in the special climatic peculiarities of any given mountain resort. A place may be freely exposed to the prevailing summer winds, or it may be shut off from them by a mountain barrier, or by forests. There are hot valleys, even in the White Mountains of New Hampshire. A favorable location with reference to cool mountain winds may make the difference between a hot and oppressive night and one which provides refreshing sleep. Such local differences are quite worth consideration in building a summer cottage.

From the point of view of health, many of these mountain districts are famous for their immunity from hay fever, and for the benefit which the open-air life gives in many cases of pulmonary and bronchial disorders, in general debility, and in cases of overwork and nervous exhaustion. The early autumn, with its exhilarating days, its crisp, cool, often frosty nights, and the wonderful coloring of its autumn foliage, is the most stimulating and in many ways the most attractive season, but it is a time when most of the summer visitors have already departed to their city homes.

It is unnecessary to enumerate the many well-known resorts of the White Mountains. Good advertising, luxurious accommodations, a

'catchy' name—these and other factors may at any time bring into prominence a new hotel, erected in what was before an abandoned forest.

The Catskills, close to New York City, are now almost overcrowded during the hotter months. "The gentle loveliness of a hill country" has made parts of the Berkshire Hills in Massachusetts a veritable garden of beautiful estates. The Green Mountains of Vermont, less rugged than their neighbors, the White Mountains of New Hampshire, are dotted over with peaceful villages, and attract a numerous summer population.

Of these northeastern mountain groups, the Adirondacks are the most widely known as a health resort, and this chiefly because of the remarkable success which has been accomplished in the altitude and open-air treatment of tuberculosis at the "Trudeau Sanatorium," founded by the late Dr. E. L. Trudeau, at Saranac Lake Village. It is the perfection of medical care and proper hygiene, and the open-air life, rather than any peculiar climatic quality, which has given the Trudeau Sanatorium its richly-deserved reputation. The Adirondack "wilderness" offers many attractions to summer vacationists, with its dense forests; its many sparkling lakes and ponds; its mountain peaks; its varied inducements to a healthy, active, outdoor life. The pure, dust-free air; the tempered summer heat; the comforts and luxuries of the hotels, the accessibility, combine to give the very name of the Adirondacks a suggestion of enjoyment and peace, and above all, of health. Lake Placid, Saranac Inn, Paul Smith's, are familiar names. The Adirondacks, like all other places, have their climatic drawbacks. Occasional hot spells; frequent summer afternoon showers and thunderstorms, and nocturnal fogs over and in the immediate vicinity of the lakes and in the valleys, are among these. Saranac Lake Village is an all-the-year health resort and, as has already been noted, there is an increasing use of the Adirondacks by those in search of winter outdoor sports. The winters are rough and hard; spells of extreme cold are frequent in the valleys; there are many storms, much cloudiness and abundant snowfall. But there are also many bright, crisp, exhilarating winter days.

The coast, as well as, and often to a greater degree than the mountains, gives relief from the summer's heat (II, b). The whole New England seaboard, from Mt. Desert on the north to the shores of Connecticut on the south, is a succession of summer resorts and of summer cottages. Long Island and then New Jersey extend this line still farther south. With its cool ocean waters; its picturesque and rugged shore-line; its numerous bays and rocky islands and good beaches, the New England coast attracts vacationists from many parts of the United States. The Maine coast has exceptionally cool summers,

especially to the north. South of Maine follows the short strip of the New Hampshire coast, and then the "North Shore" of Massachusetts with picturesque Cape Ann, Gloucester, Manchester and Beverly. A majority of the native population in this whole section gains the chief part of its livelihood from the summer visitors. The general trend of the coast line is such that the prevailing summer winds (S. W.) in many places are tempered by passing over the cool ocean water before they blow onto the land. The sea-breeze brings in pure, cool, refreshing ocean air during the noon hours of many summer days. Hence the coast often escapes the extreme heat of the interior and of more southern seashore resorts which have not the benefit of such cold offshore water as flows along the northern New England coast. The stimulating and bracing qualities of this cool summer climate have been recommended by the medical profession to many convalescents from chronic illnesses, and to patients suffering from general and nervous debility, anemia and in some cases of insomnia. But the frequency of chilling fogs and of damp easterly winds is disadvantageous in most throat and lung troubles, and the climate is too stimulating for many delicate persons who lack the vitality to react properly. These cases do better in a less bracing climate. For them, the "South Shore" of Massachusetts, and the seashore resorts reaching from southern Massachusetts to New Jersey, are generally more favorable. The Massachusetts "South Shore," with the Cape Cod and Buzzards Bay resorts, and its warm ocean waters, is warmer, more equable and more relaxing than the Maine coast. It is, therefore, better in most cases of insomnia, mental and nervous exhaustion, overwork, and convalescence. Its fogs and dampness are, however, a drawback. Martha's Vineyard and Nantucket, both of them islands to the south of Cape Cod, have even more equable conditions and smaller diurnal temperature ranges than those of the mainland. All their winds blow off the warm ocean water. Rhode Island has its Newport and its Narragansett Pier. Connecticut and Long Island offer many additional seashore residences. New Jersey may be taken as the southern limit of the "Northern Summer Seashore Resorts." The coast of New Jersey is practically one long line of health and pleasure resorts. The best known, and most consistently and widely advertised of these is Atlantic City, with a long and growing list of luxurious hotels; its famous "Board Walk," and its typically American seashore amusements. These attractions, combined with easy accessibility from New York, Boston, Philadelphia, and other large cities, and the excellent bathing facilities, ensure the popularity of Atlantic City. In summer hot spells, the sea breeze gives welcome relief. And even the offshore winds blow over a narrow stretch of salt water which separates the sand bars on which the city is built from the mainland. Atlantic City

has also become a much-frequented winter resort, especially by invalids and by vacation-seekers from the neighboring cities. There is a general impression that its winter climate is quite different from that of the rest of this part of the country. This is a mistake. The New Jersey coast is still within the storm-control of the northeastern United States. It has winter rains and snow, and cold waves, and much cloudiness, and frequent temperature changes. Its easterly winds are damp and chilly. On the other hand, however, the very rapid poleward temperature-gradient along the Atlantic coast in winter (2.7° Fahr. in January per latitude degree) inevitably gives New Jersey the advantage of mean winter temperatures somewhat higher than those farther north. Owing to the latitude and the location immediately on the ocean, the snowfall is less than inland, or in higher latitudes. The sandy soil dries quickly and warms rapidly, so that the snow which falls does not remain long on the ground. Bright, fine winter days show a considerable degree of diurnal warming.

It should be remembered that a large part of the reputation of Atlantic City, and of many other places, rests upon artificial conditions. In the case of Atlantic City itself, most of the "Board Walk" is sheltered from the northwest winds. On cold or stormy days people stay indoors; shut themselves up in glass-enclosed sun-parlors; venture out on the Board Walk in covered wheel-chairs, or sit and walk in sheltered places. Being away from home, and having no duties which call them outdoors, no matter how inclement the weather, they are naturally more or less unconscious of what the weather is. Advantage is taken of being out and of enjoying the warm sunshine and tonic air on all fine days, and, as so often happens, the "change" which benefits is more the rest, freedom from worry, and new and, to most people, diverting surroundings, than any marked difference in climate. As a winter and early spring health resort, the New Jersey coast is recommended for those who are suffering from overwork, insomnia, throat troubles; for "convalescents from acute diseases"; for many elderly people and those whose vitality is lowered—for all of whom comfortable accommodations, good food, pleasant surroundings, and somewhat less strenuous physiological adjustments to severe weather changes are desirable. Lakewood, N. J., while not on the immediate coast, may also receive mention here. Situated on the dry sandy soil of the pine belt of New Jersey, with somewhat warmer and more genial winters than prevail farther north, with clean, dust-free air and with protection against the coldest winds, Lakewood was formerly a health resort, but has now become largely a winter pleasure resort.

The third group of northern summer resorts is in the interior, neither in the mountains nor on the seashore and may be classed as intermediate (II, c). Here come the Maine woods and Rangely and

other Lakes in Maine and the Lake Champlain and Lake George districts. Beautiful and varied scenery; extended forests, relatively cool stimulating summers; the opportunity for camping and fishing and for living a simple outdoor life, have here brought to many thousands of mentally and physically tired city folk rest and relief and fitness for their winter's work. For sufferers from hay-fever, and for many persons for whom the northern sea coast is too damp and too stimulating, these intermediate stations have proved highly beneficial.

The Great Plains

The Great Plains constitute a natural and logical province from the viewpoint of climate alone, but on account of their broad expanse of remarkably uniform topography, the similarity and the disadvantages of some of their general climatic characteristics, and the lack of local scenic attractions, they have not developed any climatic health resorts in the strict sense of the term.

The Western Mountain and Plateau Region

The great mountain and plateau region of the West, extending from the eastern foothills of the Rocky Mountains to the Cascade—Sierra Nevada divide, has altitudes sufficiently great to give true "mountain climates", with their special features of strong sunshine, dry air, and strong diurnal ranges of temperature. Combined, as they are in the western United States, with a small annual rainfall, comparatively few general storms, and little cloud and fog, such climates have distinct advantages for many invalids. Furthermore, with a great variety of topography and of altitude—lofty mountains, elevated plateaus, deep valleys, low-lying deserts—this great western region embraces a wide variety of local climates. Colorado has become famous the world over for the success which has there resulted from the altitude treatment of pulmonary tuberculosis. As Dr. C. Theodore Williams expressed it, "the favorable results (of the climate) . . . may be seen in the large number of former consumptives whom it has rescued from the life of invalidism and converted into healthy and active workers."[4] The development of the muscles of the organs of respiration; the resulting expansion of chest and lungs; the improved circulation; increased heat production; better appetite, a general stimulation of various organic functions—these are among the effects of the altitude cure which are helpful in raising the vitality and in giving the body the power to overcome the ravages of the tubercle bacilli. There are, however, a good many classes of tubercular cases for whom considerable altitudes are too stimulating, or even distinctly injurious, and who do better nearer sea level, where the climate is less stimulat-

[4] C. T. Williams: "The High Altitudes of Colorado and Their Climates," Quart. Journ., Roy. Met. Soc., Vol. 19, 1893, pp. 65-82.

ing, and where there is less danger of overworking the heart and blood vessels. Such cases are those of elderly patients, those with diminished vital powers and those suffering from insomnia, cardiac and bronchial affections. The winters of Colorado are marked by an abundance of fine, crisp, sunny days and little snowfall except on the higher mountain slopes, where it accumulates to great depths. Lower down snow falls much less frequently, melts rapidly and offers no serious obstacle to an open-air life. The summers have warm days and cool nights, with frequent local showers and thunderstorms in the mountains. In the foothills region the high dusty winds of the warmer months are a distinct drawback. As compared with the northern tier of states, especially in the eastern part of the country, there are in Colorado few general storms, even in winter. The winter's cold and the heat of the summer days are much more easily borne in the dry mountain air than is the case with the same temperatures in the more humid east. The large diurnal ranges of temperature usually ensure refreshingly cool summer nights and relatively warm winter days. Invalids can as a rule be out of doors for several hours a day, even in midwinter, and need only light wraps in the strong sunshine. The western mountains are so far from the great eastern centers of population that they have not in the past attracted such great numbers of summer vacationists as frequent the mountains and seacoast of the northeastern sections. But those who are in search of an outdoor life in a rugged country of great scenic beauty are going to Colorado in larger numbers each year, and the regular "tourist travel" to the Yellowstone and Glacier National Parks, and to other favored districts of great natural wonder and beauty is increasing annually.

What has been called by the late Dr. S. E. Solly the "Invalid Belt" of Colorado varies in altitude from 4500 to 8000 ft., and extends from Middle and Estes Parks to Colorado Springs. The latter is perhaps the best known of all the Colorado health resorts, especially for those predisposed to or afflicted with tuberculosis of the lungs. A considerable part of the population of Denver has settled there for reasons of health. Manitou Springs is another health resort. The climate of the region which these cities represent is also favorable to other classes of cases which need an open-air life and not too great a stimulation of various bodily functions. At these, and other places in the "Invalid Belt," special attention is paid to the care of consumptives. Expert medical practitioners, who are skilled in the treatment of tuberculosis, are available. Excellent accommodations are provided. Everything has been done to aid the cure, for the accomplishment of which the high, dry, sunny climate of Colorado has proved to be so peculiarly well adapted.

The so-called "Parks" lie west of the Colorado Front Range. They are sheltered intermont basins or valleys, of 6000—8000 ft. altitude, with scattering pine-tree growth, of a park-like character which gives them their name. Some of these parks are well frequented summer resorts, but there is, as yet, insufficient provision for invalids.

South and southwest of Colorado come the mountains and plateaus and valleys of New Mexico and Arizona, and then, along the southern border of the United States, are the low lying deserts and irrigated valleys of the driest portion of the country. It is highly significant that well south of Colorado, in the highlands of New Mexico, at Fort Bayard and at Fort Stanton, the United States Government has established its consumptive sanatoria for the Army and Navy.[5] Of this general region Dr. W. A. Hammond, formerly Surgeon-General of the Army, wrote: "New Mexico is by far the most favorable residence in the United States for those predisposed to or afflicted with pthisis," and Dr. W. M. Yandell, of El Paso, has said that if a mild climate during the cold season is desired, New Mexico and Arizona, south of latitude 35°, furnish by far the best winter climate in the United States for consumptives[6]. Northern New Mexico and Arizona have very much the same climatic advantages as does Colorado for the altitude treatment of tuberculosis, but are even less subject to cyclonic weather changes by reason of their somewhat lower latitude. Their winters are also milder for the same reason, but occasional spells of extreme cold and snowstorms are to be expected at the higher levels. The early mornings and evenings are usually frosty; the noon hours are warm and bright. The tonic, invigorating quality of the dry sterile air; the enjoyment and encouragement which comes from an abundance of bright sunshine; the very small winter precipitation, with a minimum of rainy and cloudy days; the possibility of open-air treatment throughout the cold season; the wonderful and varied coloring of the mountains; the glories, the bigness and the appeal of the desert—these are among the attractions of the Great Southwest. The summers are long and hot, and too debilitating for many invalids. The mountains then have an advantage over the lowlands, owing to their more comfortable nights, due to the marked diurnal variation in temperature and, often, to the occurrence of cool, mountain breezes. On the desert lowlands of the south, the summer heat is more intense, and lasts longer. The dryness of the air however helps to make these very high temperatures endurable, and sunstrokes are traditionally unknown. A distinct drawback to a

[5]Since June 15, 1920, the hospital at Fort Bayard has been in charge of the U. S. Public Health Service, and is now known as "Hospital No. 55, Fort Bayard." The hospital at Fort Stanton is "U. S. Marine Hospital No. 9." There is also a U. S. Naval Hospital at Fort Lyon, Colo.

[6]Quoted by Solly, loc. cit., p. 276.

summer sojourn in most parts of the semi-arid Southwest, especially on the low-lying plains, is the frequency of high, dusty winds. In many places this dust is alkaline, and is very irritating to the mucous membranes. As health resorts, such localities are obviously undesirable, if not altogether impossible.

While fully recognizing the many remarkable cures which have been accomplished in the cases of thousands of tuberculous patients when such persons were sent out in time; were properly advised as to the best place of residence, and were financially able to make the best possible use of their opportunities, it is undeniable that many serious mistakes have been made by the medical profession in advising their invalids to go to the Southwest. Such mistakes arose largely from an inadequate knowledge of the actual climatic conditions. Patients have been sent out to the wrong places, and at the wrong seasons. Invalids, far advanced in the later stages of tuberculosis, have been advised to take the long journey when they were in no condition to stand the fatigue and could not afford the expense. Many have gone to the higher stations ill-prepared for the cold of winter, or to the southern towns during the intense heat of the summer. It is manifestly unfair to attribute the deaths of many unfortunate invalids to climate, when such persons came too late, and had improper care and surroundings. It is as true to-day as it was when Lorin Blodget stated it that "large numbers seek milder climates and perish there, whose cases should be set down to the country from which they came."[7] A difficulty in the present-day use of New Mexico and Arizona for health purposes lies in the fact that there are as yet comparatively few places in which adequate provision is made for invalids. As a health resort, the Southwest is by no means fully developed. Santa Fé, Las Vegas, Albuquerque, in New Mexico (5000—7000 ft.), are fairly typical and are used as all-the-year health resorts for certain classes of lung cases. In Arizona, Phoenix, at a low altitude, Prescott and Flagstaff at greater elevations, are representative stations. El Paso, in extreme western Texas, has similar conditions to those of southeastern New Mexico at the corresponding altitudes. It also offers a favorable climate for invalids in winter but is too hot in the long summers.

The Pacific Coast

For many centuries the Mediterranean climates of the Old World have been lauded in song and in story. For generations, the Riviera has been a favorite resort where invalids have sought health, and where an escape from the rigors of a cold and inclement winter has been found by those who have had the time and the means to leave their

[7]Loc. cit.

northern homes. The sub-tropical belt, which has its greatest extension in the classic Mediterranean region, combines many of the qualities which, taken together, probably make as nearly "ideal" a climate, for the majority of people, as can be found. Situated far enough from the equator to be spared continuously high and enervating temperatures, yet near enough to it to escape the extreme cold of higher latitudes, these transitional sub-tropical belts are highly favored. With prevailing fair skies and abundant sunshine during most of the year, equable temperatures and generally moderate winter rains, "Mediterranean climates," as they have come to be called, possess many advantages which fit them to be health resorts. The long list of European "resorts" stretching along the shores of the Mediterranean Sea, in Italy, France, Spain and Africa, bears abundant witness to this fact. In the United States, Southern California, with similar climatic controls and characteristics, ranks high in the estimation of the medical profession, and in the minds of countless thousands who, in good health, have there sought, and found, pleasure and relaxation.

The Pacific Slope, with its great latitudinal extension, its snow-capped mountains and its broad and fertile valleys, embraces a great variety of climates. It is, however, the southern coast of California which is the real health resort, and it is therefore to that district alone that this discussion relates. A conservative estimate would indicate that fully three-fourths of the Eastern visitors to Southern California find their attraction in its climate and in the outdoor life which that climate makes possible, in the midst of vineyards, and orange groves and gardens of roses. The luxurious hotels make every possible provision for visitors, and the social intercourse with people from all over the country is an added element in the attraction for many. The essential features of the climate from the standpoint of health are its mildness and equability, without enervating qualities; the relatively mild winters and cool summers; the short winter rainy season, without snowfall and with rare frosts; the absence of sudden and extreme weather changes. Even in the so-called "rainy season" of winter, the rains are light; they are not steady and continuous, usually lasting but two or three days at a time and separated by much longer spells of fine sunny weather. The mountain barrier of the great Sierra Nevada and Cascade Ranges keeps out the extremes of winter cold which are found over the interior districts to the east of the mountains. In the "dry season" of summer, mild and nearly continuously fine weather is the rule.

Southern California has an all-the-year round climate. It is frequented at all times. Winter and spring, however, are the favorite seasons. It is then that the attractions of outdoor life are most appealing, the vegetation is green and fresh, and the great throng of visitors from

the northern and eastern parts of the country, escaping from the severe winters of the interior and Atlantic Slope, take the long overland journey in order to be warmed by the California sunshine, to enjoy sea-bathing, and to revel in a tempered climate where there is no snow and ice, and where fruits and flowers and green leaves replace the bare trees and frozen ground of the East. Even the most enthusiastic native of the Pacific Slope must be satisfied with Blodget's reference to "the elastic atmosphere and bracing effect" which "constitute a striking difference from those of the Eastern States." There is no climate on the Coast "which is not the reverse of enervating. . . All residents concur in pronouncing it more favorable to physical and mental activity than any other they have known, from whatever quarter they come."[8]

The health district of Southern California lies south of latitude 35° S., and is separated from the interior by mountains which border the coast. It is a country of fertile valley and plain. San Diego, Coronado Beach, Santa Barbara, Los Angeles, Pasadena, are names as familiar as San Remo, Nice, Mentone and Monte Carlo. Most of the resorts are on or close to the coast, and at a low altitude. They have advantages, and some disadvantages, on that account. The special topographic surroundings of each station contribute something towards giving it certain local characteristics, but in the main, the climatic conditions are everywhere similar. On the immediate coast, the special features are the fog, the dampness, and the prevalence of cool onshore breezes. The fogs are chiefly nocturnal, and spring and summer phenomena. The diurnal onshore breeze, from the cool Pacific waters, is of great help in tempering the heat of summer, but brings a chill which is trying to many delicate persons, and demands the protection of warmer clothing than the majority of visitors, unfamiliar with the details of the local climates, at first think necessary. The high relative humidity, resulting from the proximity to the sea, the fog and the onshore winds, is a factor not usually expected. It is a prevalent idea, even in the minds of many experienced medical practitioners, that the small annual rainfall which, so far as actual precipitation is concerned, ensures a "dry" climate, is necessarily accompanied by a low relative humidity. The late Dr. S. E. Solly expressed the following opinion, which may be taken as authoritative: "This Pacific coast climate is damp and presents its claims to sufferers on the grounds of equable temperatures and sunshine. It lacks the dry air and tonic, stimulating qualities of the elevated inland plains, but offers less shock to the system from rapid changes." If an invalid "needs the element of absolute dryness with low altitude and sunshine, he will hardly find them together except along the low plains of Arizona and New Mexico; that is while the barren inland country of California is

[8]Loc. cit.

dry, it lacks the conveniences of civilization which cannot be obtained short of the towns of Phoenix, Tucson or El Paso." And again, "It should be thoroughly understood by the Eastern visitor in search of health that if he seeks more days of sunshine and opportunities for outdoor life, with an equable temperature and an average humidity a little greater than that of New York or Boston, he can find what he desires at Santa Barbara or San Diego."[9]

The damp, cool night air on the coast, not infrequently combined with fog, is thus a climatic feature which is not to be ignored in the treatment of invalids. Such persons can, of course, to a certain extent escape this condition by remaining indoors at night.

In climatotherapy, Southern California has in the past been much used for tubercular cases; for many cardiac affections; for insomnia, nervous disorders and for persons of somewhat lowered vitality. For many invalids, especially those with throat and lung troubles, the "back country," among the hills, offers more suitable conditions than the damper, chillier, and more trying seacoast. Redlands, and Riverside are representative of the interior district, somewhat back from the coast and at higher elevations than the stations directly on the ocean.

Although mention has been made of certain of the least desirable climatic features of Southern California, it cannot be too emphatically stated that his region has, on the whole, a remarkably favorable combination of climatic conditions. It even possesses certain advantages over the climates of the most famous Mediterranean resorts of Europe. "Here", as the late Charles Dudley Warner wrote, "is our Mediterranean. Here is our Italy."[10] And here, it may be added, countless millions in the years to come will seek, and will find, health and strength and a wonderful exhilaration in the joy of living.

[9]S. E. Solly: Medical Climatology, p. 312.
[10]C. D. Warner: "Our Italy."

THE PROGRESS OF SCIENCE

HENRY ANDREWS BUMSTEAD

Professor Bumstead, of Yale University, whose admirable address on the History of Physics is printed in the present issue of the *Monthly*, died suddenly on the night of December 31, at the age of fifty years. He had been in attendance on the meetings of the Physical Society at Chicago, of which he was a past president, and active in numerous conferences and committee meetings held during convocation week. The writer of this note was in conference with him concerning the organization of the Science Service, endowed by Mr. Scripps, until midnight on Thursday and again through Friday afternoon. His clear judgment and wise council were in constant evidence, and he appeared to be in the best of health. On Friday evening he took the train for Washington; on the following morning he was found dead in his berth.

Bumstead was the chairman of the National Research Council for the present year, succeeding Dr. James Rowland Angell, who now assumes the presidency of Yale University, where Bumstead was professor of physics and director of the Sloane Physical Laboratory. He remarked at Chicago that he was ready to devote this year to the odd jobs of science, but that he planned at the end of it to return to the research work interrupted by the war. This work was concerned with radioactivity and the Röntgen rays. He was especially interested in photoelectric effects, delta rays and the theory of electrons.

In *Nature* for February 5 will be found an appreciation by Sir J. J. Thomson, with whom Bumstead worked at Cambridge and with whom, as president of the Royal Society, he was associated during the war period. Professor R. A. Millikan, with whom Bumstead had been closely associated both as a physicist and in the conduct of the National Research Council, writes in an article printed in the issue of *Science* for January 25:

"When in 1917 the important and difficult post of scientific attaché in London was created, Bumstead was the only man considered, for no scientist in this country had his tact, his judgment, his knowledge of England, and his ability to assist in bringing about what was then, and what is now, the most important need of the modern world, namely, the cooperation and mutual understanding of the two great branches of the Anglo-Saxon race. Bumstead's success in London was extraordinary. The British liked and trusted him. Admiral Sims and our own War Department placed large responsibilities upon him, and his office became the center of a very active and very important service. Young American officers who went abroad on scientific missions found him the center of their contacts and the prime source of their usefulness. They all became his devoted admirers. Not one or two but a dozen or more of both British and American officers who came to Washington during the war told me that they owed their success in their work in England and the continent primarily to Bumstead, and counted it the most valuable part of their experience that they had had an opportunity to become acquainted with him. One of these officers described him as the most influential American in England."

"He had a brilliant analytical mind, profound scholarship, exceptional critical capacity, excellent judgment, an extraordinary winsome personality, the finest culture, and a great heart. His personal scientific contributions were important, though they had been much interfered with by his none too rugged health. His effect upon American physics, however, was not limited to his own sci-

HENRY ANDREWS BUMSTEAD

entific papers, but he exerted a powerful influence upon his pupils and upon his fellow physicists. It is not merely American science, however, which can ill afford to lose him twenty years before his time. American life in all its aspects is sadly in need of men of Bumstead's type. The cause of sanity, of culture, of Anglo-Saxon solidarity, of scholarship, of science, of world civilization, all suffer irreparably through his death."

AWARD OF THE NOBEL PRIZE TO PROFESSOR AUGUST KROGH

In Stockholm on last December 10, Dr. August Krogh, professor of zoophysiology in Copenhagen University, received the Nobel Prize in Medicine for the year 1920. The address of presentation was made by Professor J. E. Johansson of the Karolinska Institute of Stockholm. The award was given Dr. Krogh in recognition of his studies on the "capillariomotor mechanism." Until recently the conception of capillary function generally held in medical science has been that the number of open capillaries in any tissue depends upon the blood pressure in the small arteries which connect with these capillaries. As the blood pressure increases, for example, due to physical exercise, more and more capillaries open up to receive blood supply and thus accommodate the increased circulation.

Dr. Krogh who, during the past few years has made noteworthy researches in the general field of the physiology of respiration, clearly saw that if the capillaries act in this way, opening only in response to the stimulus of blood pressure and in number according to the height of the blood pressure, then the different capillaries of any tissue must vary in their susceptibility to this stimulus. Consequently if the animal organism is resting or fairly quiet, the blood supply would tend to flow in certain fixed capillary channels, viz, those which have the slightest resistance, hence some of the body cells adjoining capillary walls would be well supplied with oxygen while others would be in constant danger of suffering from oxygen want. When studying the matter experimentally in living tissues, he observed that no one capillary or group of capillaries functioned continuously. The capillaries are constantly changing in caliber. After one opens and receives blood supply it tends to close, while others in neighboring parts of the tissue open and provide new channels for circulation. There is thus a rotation or sequence of functioning so that all the capillaries receive in time their supply of fresh oxygenated blood. Further experimentation by Dr. Krogh has shown conclusively that the dilatation of the capillaries is not primarily dependent upon the blood pressure. Direct mechanical, thermal or chemical stimulation may produce dilatation of both capillaries and arteries and when the stimulus is sufficiently strong, the effect spreads to an area greater than that stimulated. The experiments indicate that the natural condition of capillaries in healthy tissue is that of tonic contraction due to local reflex action in the capillary walls and that the blood carries some substance as yet unknown which acts as a stimulus to this contraction, hence when the capillary receives blood, it begins to contract and after the stimulating substance is exhausted, it dilates to receive a fresh supply. The identity of the substance responsible for the tonic action of the blood has not been proved, but Dr. Krogh has shown it cannot well be oxygen.

Many research workers throughout the preceding years have noted what to them seemed curious phenomena in connection with the dilatation and contraction of capillaries and have recorded these facts. This work of Dr. Krogh is outstanding in that he

DR. AUGUST KROGH

has independently observed what had previously been incidentally found, has discovered other related phenomena, and correlated these so as to prove the existence of a second mechanism controlling the circulation of the blood. The heart and arteries may be termed the first mechanism with the function of dividing and propelling the blood to the different body tissues; the "capillariomotor mechanism" finally distributes the blood throughout those minute parts of the tissue which have need for the different substances which it is carrying. The two mechanisms, although commonly functioning in harmony, are thought to be relatively independent of each other.

Dr. Krogh is scarcely forty-five years old. He received his educational and scientific training in Denmark and is a son of whom that country can well be proud. For a number of years after receiving his degree and serving as laboratory assistant to Professor Christian Bohr no suitable teaching or research position opened to him in Denmark. However, he refused to accept such a position in any other country. He made two expeditions to Greenland, the first to study the tension of carbon-dioxide in ocean water and the second to investigate the respiratory metabolism of the Eskimos. Thus, without any laboratory facilities, he literally plunged into research. A study on the expiration of free nitrogen from the body was recognized as so important so as to receive the Seegen Prize of the Imperial Academy of Sciences in Vienna. He was appointed a lecturer in physiology under the science faculty of the Copenhagen University in 1908 and was provided with a small laboratory in the fall of 1910. It is in this laboratory that most of his scientific work has been done. A visitor will gain the impression that his laboratory facilities are rather meager as regards both room and equipment and that he does not have adequate assistance. Certainly it would be a most worth while investment to provide such a man with all the assistance he can comfortably direct. His researches have covered a wide range and have been singularly concise and complete. He is a master technician, a scientific explorer by nature, a skilled interpreter and critic of scientific facts and he has much facility in writing. Most of his recent work is published in English. About his personality there is a quiet humility which strongly attracts advanced students and begets confidence in Dr. Krogh's scientific results. His mental attitude can well be illustrated by a sentence from a recent letter to an American colleague. "The Nobel award came as a perfect surprise to me and when it was first told me by a journalist, I declined to believe it because, in my opinion, my work on the capillaries was so far only a promising beginning."

INTERNATIONAL EUGENICS CONGRESS

In 1912 there was held in London, under the auspices of the Eugenics Education Society, an International Eugenics Congress. A second congress was planned to be held in New York City in 1915 but, on account of the war, plans for the congress were abandoned. In the autumn of 1919, at a meeting of the International Committee of Eugenics held in London, it was agreed to hold the second International Congress in New York City in 1921. A general committee to arrange for this congress was selected by the National Research Council in the spring of 1920, and it is now announced that the Second International Congress of Eugenics will be held in New York City, September 22-28, 1921.

Of this congress Dr. Alexander Graham Bell is honorary president; Dr. Henry Fairfield Osborn, president; Mr. Madison Grant, treasurer; Mrs. C. Neville Rolfe (Mrs. Sybil Gotto) honorary secretary; and Dr. C. C. Little, secretary-general. The vice-presidents include Dr. Cesare Arton, Cagliari Italy; Dr. Kristine Bonnevie, Institute for Heredity Investigation, University of Christiania, Norway; Major Leonard Darwin, London; Dr. V. Delfino, Buenos Aires; Dr. E. M. East, Harvard University; M. Gamio, Director Archeology and Anthropology, Mexico; Sir Auckland Campbell Geddes, British Ambassador to the United States; Dr. Corado Gini, Rome; Hon. Mr. Justice Frank E. Hodgins, Supreme Court of Ontario; Dr. Frédéric Houssay, Paris; Dr. H. S. Jennings, Johns Hopkins University; G. H. Knibbs, Melbourne; Dr. Herman Lundborg, Upsala; Dr. L. Manouvrier, Paris; M. L. March, Paris; Dr. Jon Alfred Möjen, Christiana; Dr. T. H. Morgan, Columbia University; Dr. R. Pearl, Johns Hopkins University; Dr. Edmond Perrier, Paris; Dr. Ernesto Pestalozza, Rome; Dr. V. Guiffrida, Ruggieri, Italy; Professor R. Vogt, University of Copenhagen; and Professor Wille, University of Christiania.

SCIENTIFIC ITEMS

We record with regret the death of Sherburne Wesley Burnham, professor of practical astronomy in the University of Chicago and astronomer of the Yerkes Observatory; of Charles Henry Fernald, emeritus professor of zoology at Amherst Agricultural College; of Wilhelm von Waldeyer, professor of anatomy at the University of Berlin, and of Alfred Gabriel Nathorst, the Swedish geologist.

Dr. James Rowland Angell has been elected president of Yale University to succeed Dr. Arthur Twining Hadley at the close of the present university year. Dr. Angell is a son of the late President Angell of the University of Michigan, and a graduate of that university of the class of 1890. He has been professor at the University of Minnesota, professor, dean and acting president of the University of Chicago, chairman of the National Research Council, and president of the Carnegie Corporation. Dr. Angell is a distinguished psychologist, having been president of the American Psychological Association and being a member of the National Academy of Sciences. The Yale Corporation announces that it has endeavored to choose for its head the ablest educational administrator available in the United States, irrespective of the college of his graduation or the place of his residence.

The Carnegie Corporation of New York has entered into an agreement with Leland Stanford Jr. University, by which a food research institute is to be established at the university for the intensive study of the problems of production, distribution and consumption of food. The corporation expressed hope that the new organization will in time be known as the Hoover Institute. The corporation will provide $700,000 for its support for ten years. Dr. C. L. Alsberg, Chief of the Bureau of Chemistry of the U. S. Department of Agriculture, has been elected the first director.